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Impact of Reduced Dose Limits on NRC Licensed Activities

Major Issues in the Implementation of ICRP/NCRP Dose Limit Recommendations

Draft Report for Comment

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Prepared for
U.S. Nuclear Regulatory Commission

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Abstract

This report summarizes information required to estimate, at least qualitatively, the potential impacts of reducing occupational dose limits below those given in 10 CFR 20 (Revised).

For this study, a questionnaire was developed and widely distributed to the radiation protection community. The resulting data together with data from existing surveys and sources were used to estimate the impact of three dose-limit options; 10 mSv yr^{-1} (1 rem yr^{-1}), 20 mSv yr^{-1} (2 rem yr^{-1}), and a combination of an annual limit of 50 mSv yr^{-1} (5 rem yr^{-1}) coupled with a cumulative limit, in rem, equal to age in years. Due to the somewhat small number of responses and the lack of data in some specific areas, a working committee of radiation protection experts from a variety of licensees was employed to ensure the exposure data were representative.

The following overall conclusions were reached:

(1) Although 10 mSv yr^{-1} is a reasonable limit for many licensees, such a limit could be extraordinarily difficult to achieve and potentially destructive to the continued operation of some licensees, such as nuclear power, fuel fabrication, and medicine.

(2) Twenty mSv yr^{-1} as a limit is possible for some of these groups, but for others it would prove difficult.

(3) Fifty mSv yr^{-1} and age in 10s of mSv appear reasonable for all licensees, both in terms of the lifetime risk of cancer and severe genetic effects to the most highly exposed workers, and the practicality of operation. In some segments of the industry, this acceptability is based on the adoption of a "grandfather clause" for those people exceeding or close to exceeding the cumulative limit at this time.

Information for fuel fabrication, waste management, manufacturing, well logging, and industrial radiography is sparse and such data is required for a firm understanding of the potential impact of any reduction in the dose limits.

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Executive Summary

The revised Nuclear Regulatory Commission (NRC) regulations 10 CFR 20 were based largely on the 1977 recommendations of the International Commission on Radiation Protection (ICRP), as interpreted and promulgated by the Environmental Protection Agency (EPA) in 1987. Since then, the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), the National Research Council Committee on the Biological Effects of Ionizing Radiation (BEIR), and the International Commission on Radiological Protection (ICRP) have published new information indicating that the risk associated with exposure to ionizing radiation is somewhat greater than that used by the ICRP and others in 1977. This increase reflects additional cancers found in the Japanese survivors of the atomic bombings, new dosimetry, and the adoption of a projection model which accounts for the excess cancer cases that are expected to occur in those survivors who are still alive.

The ICRP recommended a dose limit of 100 mSv in 5 years (10 rem in five years) in its 1990 recommendations. The National Council on Radiation Protection and Measurements (NCRP) in 1987 recommended an annual limit of 50 mSv yr^{-1} (5 rem yr^{-1}) and suggested that no individual should exceed a cumulative dose equal to his/her age in 10s of mSv (age in rem). This suggestion has been raised to the level of a recommendation in the 1993 Recommendations of the NCRP. Many countries in the world are drafting new regulations adopting the ICRP system.

This study was requested by NRC to obtain a preliminary estimate of the potential impacts to NRC licensees of any reduction in the dose limits. In general, the past in-depth reviews of the impact of lowering dose limits were based on an assumption that there would be no reduction in the source terms, no improvement in equipment (remote tooling and surveillance), nor any increase in the productivity of radiation workers.

Three approaches were used in this study. The first was the development and distribution of a questionnaire designed to solicit and evaluate information on the potential impacts of decreased dose limits from a wide variety of licensees. The second approach was the review and analysis of previous surveys on dose impacts and other data collections. These surveys were conducted by the Edison Electric Institute (EEI) Health Physics Committee, the Department of Energy (DOE), Office of Health and Safety, and the Brookhaven National Laboratory (BNL) ALARA Center. The data collections are those of the NRC Radiation Exposure Information Reporting System (REIRS) and Environmental Protection Agency (EPA) 1984 Report on Occupational Exposure.

The third approach was to use a working committee to validate and extend the data obtained from the questionnaire, and also review and comment on this report. This committee was composed of radiation protection experts from various sectors of NRC licensees, together with individuals from Nuclear Management and Resources Council (NUMARC), DOE, NRC, and the BNL ALARA Center.

Where possible, the data for 1989 was used as the basis for this report to allow meaningful intercomparisons. The BNL High Dose Group Study was based on 1988 data, and the EPA Report was based on data of 1984 and earlier. Although the data for 1990 suggests a reduction in individual and collective dose has taken place, the overall conclusions drawn from this study remain valid.

Examples of costs associated with reducing the source term in nuclear power plants were obtained from the NUREG/CR-4373, "Compendium of Cost-Effectiveness Evaluations of Modifications for dose Reduction at Nuclear Power Plants," (Baum and Matthews, 1985).

From the information given in this report and that offered by the working committee, several tentative conclusions can be drawn.

The analysis suggests there would be minimal impact on collective doses, on costs of modifying facilities, or on annual radiation-protection costs under the combined limit of 50 mSv yr^{-1} (5 rem yr^{-1}) and cumulative dose in 10s of mSv (rem) equal to age in years. The lifetime risk associated with this limit - to an individual maximally exposed - would be slightly less than that incurred by a similar individual controlled by the ICRP's limit of 100 mSv in 5 years (10 rem in 5 years. However, a "grandfather clause" allowing up to 20 mSv yr^{-1} (2 rem yr^{-1}) after exceeding the age limit may be required for perhaps less than 1000 workers.

A 20 mSv yr^{-1} (2 rem yr^{-1}) limit would appear achievable, although some tasks, particularly those in medicine and in certain parts of the nuclear power industry, might prove extremely difficult to maintain. Extensive modifications, such as steam generation, maintenance, and refueling including the installation and use of robots and partial/full system decontamination, would be required for many tasks in nuclear power plants. Depending upon the extent of the modifications, the collective dose might go up or down. That is, extensive use of robots, source term reductions, and facility modifications might lower collective doses. Less ambitious modifications, less decontamination, and the use of fewer robots might keep the collective doses at about the same level while reducing individual doses; making no changes and allowing the same tasks to be performed would necessarily result in higher collective doses. The working committee suggested that with this annual limit, there could be a potential impact on safety since some inspection and maintenance might be curtailed.

For a 10 mSv yr^{-1} (1 rem yr^{-1}) limit, the risk to the most highly exposed individual would be lower than for other options, i.e. equivalent to that of fatal accidents in United States industries, but the impacts are expected to be quite serious for many of the industries which responded to the questionnaire. There are tasks, again in medicine, which under present procedures could be prohibitively expensive. For industries with large source terms, facility modifications and radiation protection costs would be extremely large (see Section 7). For these reasons, collective dose may increase substantially.

One additional issue must be kept in mind when assessing the impact of lower dose limits. That is, for licensees to ensure that doses do not exceed the regulated dose limits, they routinely use administrative limits. For example, with a regulatory limit of a 50 mSv yr^{-1} (5 rem yr^{-1}), an administrative limit of a 40 mSv yr^{-1} (4 rem yr^{-1}) might be used. At 20 mSv yr^{-1} (2 rem yr^{-1}) limit, a 15 mSv yr^{-1} (1.5 rem yr^{-1}) administrative limit might be used, and so on.

FOREWORD

On May 21, 1991, the Nuclear Regulatory Commission (NRC) published a revision to 10 CFR Part 20, "Standards for Protection Against Radiation." The rule became effective in June, 1991, and licensees were required to implement the regulations on or before January 1, 1994.

The revised 10 CFR Part 20 is based upon the recommendations of the International Commission on Radiological Protection (ICRP) in Publication 26 (ICRP 1977). In 1991, the ICRP published revised recommendations in Publication 60. These recommendations were based upon revised dosimetry and epidemiology, including the information presented in reports such as the 1988 United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR). The new recommendations include a revised occupational dose limitation approach of 100 mSv (10 rem) in 5 years, with the additional limitation that no more than 50 mSv (5 rem) be received in any one year.

In 1991, the National Council on Radiation Protection and Measurements (NCRP) recommended a lifetime limit of 10 mSv (1 rem) times age in years (NCRP Report 91). This recommendation was continued in recommendations published in 1993 (NCRP Report 116).

In anticipation of these recommendations, and as a result of the epidemiological and dosimetric information available in the last 5 years, the NRC staff initiated a study by Brookhaven National Laboratory (BNL) to analyze the potential impacts of reduced dose limits on its licensees. The results of this study are contained in this draft NUREG/CR. During the study period, a relatively small number of licensees responded to questionnaires and surveys, thereby limiting the extent to which the survey results can be assumed to be an accurate representation of the potential impacts of changed dose limits.

The NRC staff has decided to publish these results in draft form, and to solicit further comments from interested parties regarding the impacts of the different possible dose limits discussed in the NUREG/CR. These limits could take the form of annual limits, similar to those presently employed in 10 CFR Part 20; long term average values, such as recommended by the ICRP; lifetime limits, such as suggested by the NCRP; or some combination of the above. The NRC staff is particularly interested in comments on the impacts of such possible approaches, and comments on the preliminary information presented in this NUREG/CR.

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Licensees, Agreement States, and all other interested parties are encouraged to submit comments and relevant data on this draft report to:

Chief, Rules Review and Directive Branch
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Impact of Reduced Dose Limits on NRC Licensed Activities

1 Introduction

The revised Nuclear Regulatory Commission (NRC) regulations, 10 CFR 20, (NRC,1991) impose an annual effective dose equivalent limit of 50 mSv (5 rem) on occupationally exposed workers. This requirement corresponds to that given in the Environmental Protection Agency's (EPA's) 1987 Radiation Protection Guidance for Occupational Exposure-Recommendations (EPA, 1987) approved by the President. Both of these organizations based their requirements largely on the 1977 recommendations of the International Commission on Radiological Protection (ICRP) given in their Publication 26 (ICRP, 1977).

In the late 1980s, the Radiation Effects Research Foundation (RERF) updated the data on their life-span study of the Japanese atomic bomb survivors to account for the increase in cancer incidence as a function of dose associated with a revision in the dosimetry (Shimizu et al., 1987; 1988). Another increase in the risk factors resulted from a potential increase in the risk associated with further epidemiological support for the multiplicative or relative risk projection model. The National Council on Radiation Protection and Measurements (NCRP) modified their basic recommendations to reflect this preliminary data in 1987 (NCRP, 1987). The NCRP also noted the substantial decrease in the frequency of fatal industrial accidents that had been the basis for the risk-based dose limit given by ICRP in 1977.

Shortly thereafter, the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) and the National Research Council Committee on the Biological Effects of Ionizing Radiation (BEIR) produced the 1988 UNSCEAR Report (UNSCEAR, 1988) and the 1990 BEIR V Report, (NASBEIR, 1990) respectively.

Using the preliminary information from the 1988 UNSCEAR report, the ICRP began a major revision to its recommendations, beginning with a detailed review of the data. The revised estimate of the lifetime fatal cancer risk for low dose or low dose-rate exposure given in ICRP Publication 60 is ~4 x 10^{-2}Sv^{-1} (~ 4 x 10^{-4} rem^{-1}) for adults, and about 5 x 10^{-2}Sv^{-1} (5 x 10^{-4} rem^{-1}) for the total population (ICRP, 1991). Although the ICRP has changed its criteria for selecting dose limits, this increased estimate of the risk of fatal cancer alone from 1.25 to 4 x 10^{-2} Sv^{-1} (1.25 to 4 x 10^{-4} rem^{-1}) given in ICRP Publication 26 (ICRP, 1977) suggested that an annual limit of 50 mSv (5.0 rem) over a working lifetime was unlikely to be considered acceptable. Their solution, given in Publication 60, was to recommend an occupational limit of 100 mSv in 5 years (20 mSv yr^{-1}) [10 rem in 5 years (2 rem yr^{-1})] with an additional limit of 50 mSv (5 rem) in any year.

The International Atomic Energy Agency (IAEA) and the Commission of European Communities (CEC) already have begun to revise their basic safety standards to conform with ICRP's new recommendations.

In light of these developments, in 1988 the NRC requested that a preliminary study be made to analyze the potential impacts of reduced dose limits on its licensees, and to provide a technical base for making future regulatory decisions on limits. This report summarizes the results of a review on the impact of reduced dose limits to NRC licensees.

2 Historical Background and Literature Survey

2.1 1928 to 1977

The first widely accepted dose-limiting recommendations were based on keeping exposures below the threshold for observable effects (Mutscheller, 1925). By the end of the second world war, these limits, which by then reflected concern over leukemia and genetic effects, were expressed as 300 mrem/week to tissues at a depth of 5 cm or more in the body, and 600 mrem/week to the surface of the body (NBS, 1954; ICRP, 1954). These values were equivalent to the later limits of 15 rem yr^{-1} to most of the individual organs (NCRP, 1971; ICRP, 1959a), and 30 rem yr^{-1} to the skin (NRC, 1960; ICRP, 1964).

After the second world war, there was much public concern over world-wide fallout from nuclear tests (Divine, 1978). Mueller and others were convinced that for genetic effects at least, there was a linear no-threshold response (Mueller, 1927; Lea, 1947). The National Academy of Sciences-National Research Council (NAS-NRC, 1956) and the British Medical Research Council (MRC, UK, 1956) formed expert committees to examine the radiobiological evidence. The basic consideration was the need to restrict the genetic damage to both exposed individuals and to the general population. Based heavily on the dose-effect relationship for genetic effects seen in Drosophila and on the observed genetic burden seen in humans, assumed to be partly due to the natural radiation background (Haldane, 1948), the next set of limits reflected: 1) a need to limit cumulative dose, and 2) a need to restrict the cumulative dose to workers in their reproductive years below that for older workers. The resulting limits for whole-body penetrating radiation were (age - 18) 5 rem cumulative dose and 3 rem/quarter (NCRP, 1957; ICRP, 1959b).

By the early 60s, the data from the Japanese survivors of the atomic bombs began to emerge (UNSCEAR, 1962). This data, together with that from the early radiologists and British spondylitic patients, suggested that the incidence of leukemia increased as a result of radiation.

A decade later, it was apparent that the incidence of certain solid tumors also increased in the Japanese survivors, the British spondylitic patients, and women with mastitis who had been treated with X rays (UNSCEAR, 1972).

Consequently, the International Commission on Radiological Protection (ICRP), the National Council on Radiation Protection and Measurements (NCRP), and the Federal Radiation Council (FRC) all reemphasized the need to keep exposure as low as practical, practicable, or reasonably achievable.

2.2 1977 to 1987

In the middle 70s, the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR, 1977) felt there was sufficient information from the Japanese atomic bomb survivors to estimate the risks to individual organs. This led to the adoption by the ICRP in 1977 of the effective dose equivalent concept[1], with its attendant w_T values (weighting factors representing the proportion of the stochastic risk from individual tissues relative to the risk to the whole body when the body is irradiated uniformly). In addition, the ICRP "justified" the 50 mSv yr^{-1} (5 rem yr^{-1}) limit on the basis that the average dose would be less than 10 mSv yr^{-1} (1 rem yr^{-1}) and, as UNSCEAR had done, assumed that the risk from low dose, low dose-rate exposure was 2.5 times less than that seen in Japanese atomic bomb survivors. The first of these two criteria led ICRP in 1977 to eliminate the (age - 18) 5 rem recommendation.

Perhaps the greatest significance of the 1977 ICRP Publication 26 was the development of the close relationship between risk and dose limits. Simply put, an average excess risk of fatal cancer and severe genetic effects of 1×10^{-2} Sv^{-1} (1×10^{-4} rem^{-1}) was judged to be "acceptable" by the ICRP.

At the time that ICRP published their recommended occupational limit of 50 mSv yr^{-1} (5 rem yr^{-1}) (ICRP, 1977), several different sets of limits were being recommended or used in the United States.

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[1] The concept originated in ICRP Publication 26 (ICRP, 1977) although the term "effective dose equivalent"was not introduced until 1978 (statement from the 1978 Stockholm Meeting of the ICRP Annals of the ICRP, Vol. 2, No. 1. (1978).

The NCRP was recommending a limit of 5 rem yr^{-1} and (age - 18)5 rem (NCRP, 1987); the Federal Radiation Council (FRC) was recommending 3 rem/quarter and (age-18) 5 rem (FRC, 1960); both the Nuclear Regulatory Commission (NRC) and the Occupational Safety and Health Administration (OSHA) were enforcing 3 rem/quarter and (age -18) 5 rem, and the Department of Energy (DOE) were enforcing 3 rem/quarter and 5 rem yr^{-1}. During this period, the Natural Resources Defense Council (NRDC) petitioned both the EPA and the NRC to lower occupational exposure limits in the United States. The federal agencies' response to the petition eventually led to several reports on the impact of lowering the Annual Dose Equivalent limit from 5 rem to 0.5 rem.

The earliest report was prepared for Stone and Webster Engineering Corporation by Warman et al., 1978. Their basic conclusion was that a decrease in the dose limit to about 2 rem yr^{-1} would exponentially increase both collective dose and the number of additional workers needed. Below 2 rem yr^{-1}, the increase per unit dose reduction would be even greater. These results were based on the dose distribution of Pressurized Water Reactor (PWR) and Boiling Water Reactor (BWR) workers in 1976. The basic assumptions were that the dose received by workers that was above any new dose limit would have to be received by additional workers, and that the dose rates existing at the power plants at that time would be representative of future dose rates. All workers were assumed to be productive 90% of the time.

A more detailed analysis was made by the Atomic Industrial Forum (AIF) a few years later in which the impacts were analyzed by tasks (AIF, 1978). The overall conclusion, taken from a statement in the report, was "While exposure and costs do increase, manpower is considered the most significant concern." Again, it is important to recognize that AIF assumed (1) "that there will be no significant design improvements made leading to the reduction of exposure or to improved operation or maintenance", and (2) "that work in a radiation environment at commercial nuclear power plants will not be performed significantly differently at lowered exposure limits than it is at present limits."

The DOE conducted a similar study for their facilities (DOE, 1979). Rather than employ the models used in the AIF study, DOE relied on a detailed questionnaire and a review committee. However, their conclusions were no different than those of the two reports discussed above, except that the impacts occurred at slightly lower doses because DOE was then using a 5 rem yr^{-1} limit. The DOE report recommended that the concept of As Low As Reasonably Achievable (ALARA) should have greater attention than a reduction in dose limit. Also, there was more emphasis on potential facility modifications and reduction of source terms.

Fortunately, since these reports were issued, extraordinary strides in reducing exposure using the ALARA principle and restrictive administrative limits have significantly reduced collective dose without increasing the average annual dose to workers. In fact, the combination of improvements in productivity, design, and source-term reduction has decreased the average individual dose at both NRC licensees and DOE facilities over the past decade. This was most clearly demonstrated in the Naval Nuclear Propulsion Program (Schmitt and Brice, 1984), and in the commercial nuclear power industry (Brooks, 1988).

2.3 1987 to 1992

Today, the weight of new radiobiological evidence on dose limits is as important as it was in the early 1950s. The incorporation of (age -18) 5 rem into the recommendations and limits at that time was accepted with little difficulty (except, perhaps, in uranium mining and fuel fabrication). The most recent evidence from the Japanese survivors, reviewed by UNSCEAR (UNSCEAR, 1988) and the National Academy of Sciences (NAS) Committee on the Biological Effects of Ionizing Radiation (BEIR, 1990), suggests that the risks of fatal cancer and severe genetic effects may be up to 4 times greater than those estimated in 1977.

Most workers seem to have been adequately protected under the (age - 18) 5 rem dose limit. The average annual exposure to monitored workers with measurable exposure was about 230 mrem (EPA, 1984). Using the 1990 ICRP risk estimates of 5 X 10^{-2} Sv^{-1} ($\sim 5 \times 10^{-4}$ rem^{-1}) for fatal cancer plus severe genetic effects for those aged 18-65, the lifetime risk to an individual receiving the annual exposure of 2.3 mSv (230 mrem) is predicted to be $\sim 1 \times 10^{-4}$. This figure is comparable to the risk of accidental death in U.S. industry.

However, for a worker receiving 50 mSv (5 rem) in one year, these same risk estimates project a lifetime risk of attributable fatal cancer and severe genetic effects at 2.5×10^{-3}. Such an annual level of risk is comparable to that associated with the upper range of risk in mining, construction, and agriculture, including deep-sea fishing. For those few workers who may receive annual doses near the dose limit over much of their working lives, the cumulative level of risk may be unacceptable.

Reacting to the emerging information from the Radiation Effects Research Foundation (RERF) in Japan (Preston and Pierce, 1981), the ICRP issued a statement in 1987 following its meeting in Como, Italy (ICRP, 1987). The Commission suggested that: (1) revised dosimetry could increase the cancer risk/unit dose by a factor of 1.4, (2) the observed increase in the incidence of solid tumors in "younger" members of the exposed population might lead to a combined increase of a factor of 2, and (3) the relative risk projection model could increase the risk factor even further. The Commission also noted that a new set of basic recommendations would be available in 1990.

Consequently, the National Radiation Protection Board (NRPB) in England issued interim guidance in November 1987 (NRPB, 1987) in which they recommended that "... occupational workers exposure should be so controlled as not to exceed an average effective dose equivalent of 15 mSv yr^{-1}."

This NRPB Guidance is, in fact, quite similar to the 1987 recommendation of the NCRP in its Report 91 (NCRP, 1987) in which the Council stated "...the community of radiation users is encouraged to control their operations in the workplace in such a manner as to ensure, in effect, that the numerical value of the individual worker's lifetime effective dose equivalent in tens of mSv (rem) does not exceed the value of his or her age in years." Both approaches would lead to lifetime doses below 750 mSv (75 rem).

Both guidances reflected an expectation that risk estimates would increase and safe industries would continue to become safer.

In general agreement with other countries, the Federal Republic of Germany stated that before changing annual dose limits it will await completion of international discussion following the issuance of the 1990 ICRP recommendations. However, the German authorities made a rather dramatic change in their recommendations (Kaul et al., 1989):

> "Under the present conditions, the German Commission on Radiological Protection (SSK) recommends that the rule of minimization be applied more strictly and that in the future, in adherence to the annual dose limit of the Radiological Protection Ordinance of 50 mSv, a total dose of 400 mSv during a whole working lifetime shall not be exceeded (occupational lifetime dose)."

A comprehensive report on the impacts of dose-limit reduction was produced in 1988 for the Electrical Power Research Institute (EPRI) (Le Surf, 1988). The author suggested that although there have been significant reductions in both individual and collective doses in the U. S. nuclear power industry, basic and fundamental changes are needed if this industry is to comply with lower limits. He points out that other countries have successfully reduced exposure in three ways: first, by changing the philosophy of radiation protection, emphasizing line responsibility and training; second, by introducing aggressive measures to reduce the source term; and third, by incorporating similar approaches to prevent the buildup of radiation fields. The NRC established an ALARA Center at Brookhaven National Laboratory (BNL), which maintains a database for these issues (Khan et al., 1992; Baum and Khan, 1992; Khan et al., 1991b).

In January 1991, the ICRP issued its Publication 60, "The 1990 Recommendations of the International Commission on Radiological Protection" (ICRP, 1991) recommending a limit of 100 mSv in 5 years, with the caveat that no more than 50 mSv be allowed in any one year. The Commission's intention was to limit the lifetime effective dose to ~1 Sv (100 rem) and the average annual effective dose equivalent to 20 mSv (2 rem).

The most recent NCRP recommendations given in its Report 116, "Limitation of Exposure to Ionizing Radiation," raise the guidance given in NCRP Report 91, "Recommendation on Limits for Exposure to Ionizing Radiation," on a lifetime dose in 10s of mSv equal to age in years (lifetime dose in rem equal to age in years) to the level of a recommendation. The NCRP Report 116 also maintains the recommendation of 50 mSv yr^{-1} (5 rem yr^{-1}).

The IAEA now is revising of the Basic Safety Standards as is the CEC. The European Community is expected to have a new set of requirements based on ICRP 60 by the middle of this decade, with many other nations following soon after.

2.4 Background Summary

In general, past in-depth reviews of the impact of lowering dose limits were based on an assumption that there would be no reduction in the source terms, no improvement in equipment (remote tooling and surveillance), nor any increase in the productivity of radiation workers. However, reductions in dose limits led to the realization that all of these assumptions may be incorrect. It is essential that any review of the impact of lowering dose limits addresses the financial impact of lowering collective doses, not simply the redistribution of existing exposure.

3 Data Gathering

In this study we proposed to use existing surveys and to obtain opinions on the impacts of reductions in the dose limit from as broad a spectrum of users as possible without resorting to an intensive site-by-site assessment. In addition to reviewing such surveys, such as the EEI, the DOE, and recent NRC-sponsored studies on dose reduction, there was a widespread distribution of a questionnaire to elicit the responders' opinion and to obtain specific data to assist in our overall assessment of the impact. Data from the NRC's Radiation Exposure Information and Reporting System (REIRS) and the 1984 EPA Report on Occupational Exposure were used to validate the survey data.

3.1 Existing Surveys

3.1.1 1992 Edison Electric Institute (EEI) Report on Dose Limits and Guidelines

Questionnaires were sent to all members of the EEI Health Physics Committee addressing the following topics: 1) current practices and experience on administrative dose-control levels, 2) cumulative dose guidelines and experience, 3) projected impacts associated with lifetime dose limits, and 4) effects of a reduced annual dose limit and of establishing a cumulative dose limit. Twenty-seven individuals replied, representing 23 nuclear utilities. These responses covered 43 Pressurized Water Reactors, 18 Boiling Water Reactors, and a High Temperature Gas Cooled Reactor, encompassing more than half the nuclear power plants (62 out of 108 units in 1989), and solicited dose data for > 14,500 and > 12,500 individuals with doses > 500 mrem in 1985 and 1989, respectively. For these two years, the number of personnel at U. S. power reactors with doses > 500 mrem was about 27,000 and 25,000, respectively.

The responses were stored in a computer database and published as graphs and tables, with the authors of the report using their best judgment to interpret the utilities' responses. The full survey is reported in the EEI Nuclear Report, "Utility Response to Questionnaire on Dose Limits" (EEI, 1991); Section 4.1 gives a brief summary.

3.1.2 Department of Energy Report (DOE) on the Implications of the BEIR V Report

In response to a request by the Secretary of Energy, the Office of Health reviewed the implications of the BEIR V report for the Department of Energy (DOE). A questionnaire was developed by a DOE Internal Review Committee to survey DOE contractors to estimate costs for additional personnel, programmatic upgrades, and engineering modifications that would be needed to comply with an anticipated reduction in the dose limits.

The questionnaire was sent to the Albuquerque, Chicago, Idaho, Nevada, Oak Ridge, Richland, San Francisco, and Savannah River Field Offices on January 30, 1990, for distribution to their contractors. Thirty-seven contractor sites responded, which operate the following types of nuclear facilities: accelerators, fuel/uranium enrichment, fuel fabrication, fuel processing, maintenance and support, hot cells, reactors (test, research, and production types), research and development, fusion, waste processing/storage, weapons fabrication and testing, tritium production, and radiography. Two significant contributors to DOE's collective dose, the Rocky Flats plant in Golden, Colorado, and Los Alamos National Laboratory in Los Alamos, New Mexico did not respond.

The scope and findings of the survey are given in the "Final Report to the Secretary of Energy; Implication of the BEIR V Report to the Department of Energy" (DOE, 1990). The results are summarized in Section 4.2 of this report.

3.1.3 Nuclear Regulatory Commission (NRC) Radiation Exposure Information and Reporting System (REIRS)

The NRC established a radiation exposure information and reporting system (REIRS) and publishes data from six of the seven categories of NRC licensees subject to the reporting requirements of 10 CFR 20.407. Selected data from NUREG 0713 Vol 12 (Raddatz and Hagemeyer, 1993), which presents data for 1990, are given in Section 4.3 of this report; it serves as one element of the process of ensuring that the survey responses provide a realistic picture of the exposure statistics. It should be noted that the REIRS data contains information from NRC licensees only. Companies that are licensed by agreement states do not report their exposures to the NRC, so the data for industrial radiography, manufacturing, and distribution of specified quantities of by-products and low-level waste do not reflect the total United States exposure.

3.1.4 Environmental Protection Agency (EPA) Report on Occupational Exposure to Ionizing Radiation in the United States

Because the U. S. nuclear industry is spread over many diverse sectors, it is very difficult to get a complete, comprehensive picture of the radiation exposure of all radiation workers. Fortunately, the Environmental Protection Agency (EPA) made a study which covers almost every sector (EPA, 1984). We analyzed their data to gain detailed information for one year over the entire U. S. nuclear industry. Although the study is several years old, it is by far the most detailed of its kind and its main conclusions are useful to the current effort. Section 4 presents our analysis.

3.2 Survey Performed for this Report

A questionnaire designed to elicit response from a wide variety of radiation users was developed (Appendix A).

A working group of technical experts (see 3.2.3) reviewed the data from the questionnaire and obtained additional data where needed.

3.2.1 Questionnaire Design

Three classes of information were judged to be important: The responders' estimate of the impact as a function of several dose limiting options; their organization's preliminary data on exposures; and lastly, their comments and suggestions. The questionnaire also solicited information about the respondent's organization and asked if the respondee could become a member of a working group to review and assess the results of the questionnaire.

3.2.1.1 Options for Potential Dose Limits

Four dose-limit options were proposed, each reflecting a rational response to the new risk estimates. The first option considered was 2 rem yr^{-1}, which was the basic recommendation in the widely circulated draft of the ICRP revision to its Publication 26 (the final recommendation was 100 mSv in five years, and less than 50 mSv in any one year).

The second option was 1 rem yr^{-1}, based on the UNSCEAR 1988 risk estimate being about 4 times the UNSCEAR 1977 risk estimate. Therefore, it might be prudent to reduce the 5 rem yr^{-1} limit to about 1 rem yr^{-1} to account for this difference. In addition, the age-related approach suggested in NCRP 91 could result in 1 rem yr^{-1} if the regulatory agency is concerned about the record-keeping of cumulative dose limits. Furthermore, perhaps this is the lowest level that could be imposed and still permit widespread use of radiation and radioactive materials.

The third option was age in rem and 5 rem yr^{-1}, which simply escalates the "guidance" given in NCRP Report 91 to a regulatory limit. It allows up to 5 rem yr^{-1} which permits the continued operation of previously designed facilities without significant modifications, but ensures that the lifetime risk to any individual will be less than 100 rem.

Fourth, a limit of age in rem and 2 rem yr^{-1} was given because a regulatory agency may want to regulate the rate of exposure more closely than option 3. In addition, this limit option appears to be closer to the ICRP's recommended limit of 100 mSv in five years, and has the advantage of restricting exposure in the early years of working life more than does option 3.

These four options are not intended as suggestions for new regulatory limits, but merely as the most probable ones which a regulator might consider.

3.2.1.2 Impacts of Reduced Dose Limits

Previous studies on the impacts of reduced dose limits usually cite increased costs and increased collective dose. The questionnaire asked that costs be broken down between those required for modifying the facility, and operating costs. The first are expected to be one-time costs, and the latter recurring costs.

3.2.1.3 1989 Dose Experience

To allow BNL to make a less subjective assessment, six items of related data were requested. The first three were the number of employees with exposure in excess of 5 rem, 2 rem, and 1 rem in 1989, data clearly related to the potential limits given in the options. The fourth item was a request for information on the number of employees whose current lifetime dose in rem exceeds their age, which would highlight any need for "grandfathering". The number of employees with measurable dose was requested to judge the weight that should be given to the specific data in the questionnaire. The annual collective dose also was requested, which, when taken with the above data, could provide information on the dose distribution, and assist in evaluating the answers about the impact on collective dose.

3.2.2 Questionnaire Distribution

The questionnaire and an explanation of its intended use was published in the July 1990 issue of the Health Physics Society Newsletter, which is distributed to the nearly 6,000 members of the society. The society is composed of scientists, engineers, and professionals concerned with radiation protection throughout the United States, so it was felt that virtually all categories of radiation users would have access to it. A letter describing the questionnaire and its availability was published in the newsletter of the American Association of Physicists in Medicine. The majority of medical physicists and medical health physicists belong to this society, so this category of radiation users was given a unique opportunity to participate.

3.2.3 Working Committee on the Impact of Reduced Dose Limits

From the inception of this study, we recognized that the questionnaire alone could not ensure that all occupational exposure practices were adequately assessed. In addition, the questionnaire might elicit subjective information which, while helpful, could lead to misinterpretation of the actual impact, particularly where there were few responses from a particular industry or practice. Therefore, a working committee was assembled composed of individuals with experience and knowledge in radiation protection from a wide variety of industries and practices. The membership included: from medical activities (Larry Brennecke and Thomas McLeod); from industrial radiography (Thomas M. Gaines); from well logging (George O'Bannion); from the university community (Howard K. Elson); from nuclear power plants (Frank Rescek); from nuclear plant contractors (Frank Roddy); from fuel fabricators (Robert Robinson); from NUMARC (Ralph Andersen and Jay Maisler); from the Nuclear Regulatory Commission (George Powers and Alan Roecklein); and from the Department of Energy (Anthony Weadock). Bruce Dionne and Tasneem Khan of the BNL ALARA Center also participated.

The working committee met on March 27, 1991 to review the data from the questionnaires. They also reviewed the study by the DOE on the implications of BEIR V to the DOE, and the BNL ALARA Center study on high-dose worker groups at nuclear plants (both are discussed elsewhere in this report). Additional data was received from the participants during the meeting, and areas requiring more information were identified.

After this meeting, questionnaires were mailed to additional radiographers, fuel-fabrication workers, and nuclear-plant contractors.

A letter in the October 1991 issue of the Health Physics Society Newsletter summarized the information from the responses received up to that point. This letter specifically requested comments and suggestions. Because there were no responses, a follow-up letter was published in the March 1992 issue. Only two responses were received by the end of May.

A second meeting of the working group was held in July 1992 when several specific comments and suggestions were made (see Chapter 5).

4 Survey Results

4.1 Edison Electric Institute (EEI) Report

4.1.1 Administrative Control Levels

In the EEI Report (EEI, 1991) twenty-seven people reported administrative control levels: six use a 5 rem annual "limit"; eight have adopted a 4.5 to 4.9 rem yr^{-1} value; eleven use an annual control level of approximately 4 rem yr^{-1} (which was the guideline published by the Institute of Nuclear Power Operations (INPO) in 1988); and two have adopted progressive levels of 2.5 rem yr^{-1}.

4.1.2 Annual Reported Doses for 1985 and 1989

Figure 4.1 (taken from the EEI Report) shows the number of workers from 11 sites with annual doses greater than 0.5, 1.0, 2.0, 3.0, 4.0, and 5.0 rem in 1985 and 1989. The data include both utility personnel (UT) and total personnel (TO) which includes contractors. Figure 4.2 (also from the same report) shows the percentage of utility personnel and total personnel with annual doses greater than these dose values for the same two years. The contractor doses are only those reported by the individual utilities and may not reflect their total dose (i.e. the sum of doses received at two or more sites).

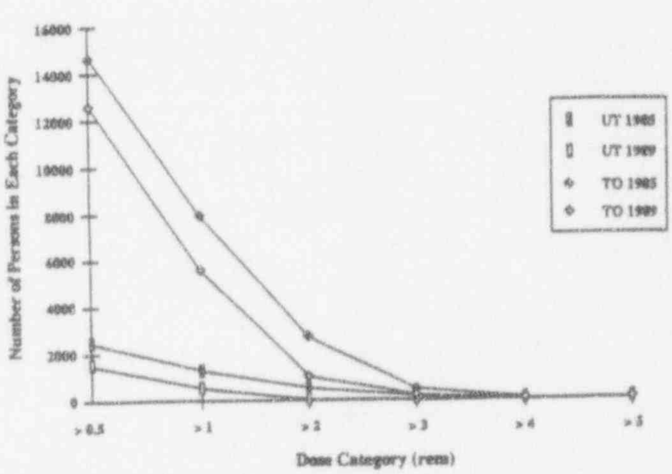

Figure 4.1 Annual Site Doses for Utility Personnel (UT) and Total Plant Workers (TO) (11 Responders)

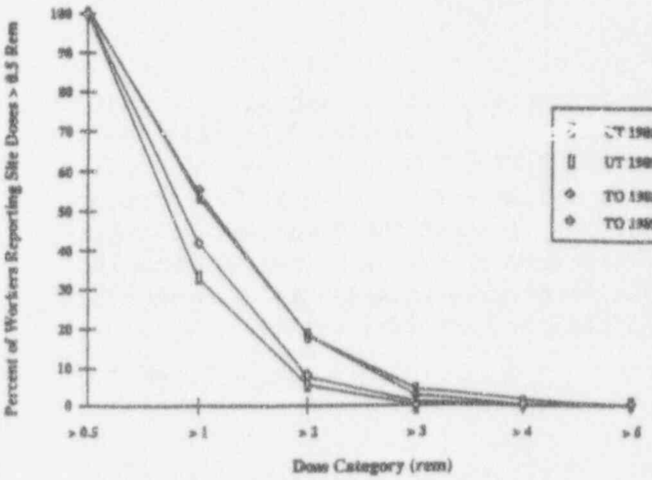

Figure 4.2 Annual Site Doses for Utility Personnel (UT) and Total Plant Workers (TO) for 1985 and 1989

There is a clear decrease in the number and percentage of both utility and total personnel above each dose value in 1989 relative to 1985. No person exceeded 5 rem yr^{-1}. About 8% (967) of the people at 11 sites had annual doses greater than 2 rem yr^{-1} in 1989.

4.1.3 Cumulative Dose Administrative Guidelines

The survey showed that 13 of the 26 responders had established some form of a cumulative dose guideline, the most common being age times 1 rem. Four have a review or reference level based on age, or a cumulative lifetime value, for which individual doses would be tracked and intervention would occur. Ten responders had not established a cumulative guideline in 1989 but most were in the process of adopting one. We noted that seven responders had adopted a cumulative-dose exemption procedure to exceed, which typically required the approval of a Vice President, Director, or Plant Manager. The report stated that "...it is likely that in a few years most nuclear utilities will have in place some form of lifetime or cumulative dose guidance". In its December 1991 guidelines, INPO urged utilities to strive to meet the NCRP recommendation of a lifetime dose not to exceed the workers age in rem.

4.1.4 Cumulative Reported Doses for 1989

Figure 4.3 (reproduced from the EEI Report) shows the number of personnel, from 19 responder sites in 1989, with cumulative doses in the categories 25-50, 50-75, 75-100, 100-150, and > 150 rem for utility and contractor personnel. The EEI Report does not show how many individuals exceed a lifetime dose of their age in rem, but rather, the number of workers younger and older than 50 that appeared in each cumulative dose interval.

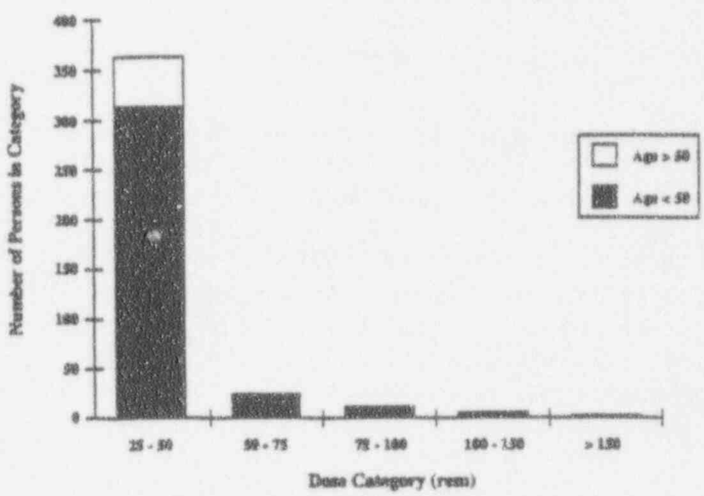

Figure 4.3 Cumulative Site Doses for Utility and Contractor Personnel for 1989 (19 Responders)

Of this total worker population, less than 50 utility and contractor personnel younger than 50 had lifetime exposures greater than 50 rem. Other findings on cumulative doses were: 1) no utility worker had lifetime doses greater than 75 rem, and 2) several contractor personnel had lifetime doses greater than 75 rem, and a couple had more than 150 rem in 1989.

4.1.5 Projected Cumulative Doses for 1994

Figure 4.4 (reproduced from the EEI Report) shows the projected number of personnel from 14 responder sites anticipated to have cumulative doses in the same dose categories listed in Section 4.1.4. These numbers are for both utility and contractor personnel projected from past data trends out to 1994.

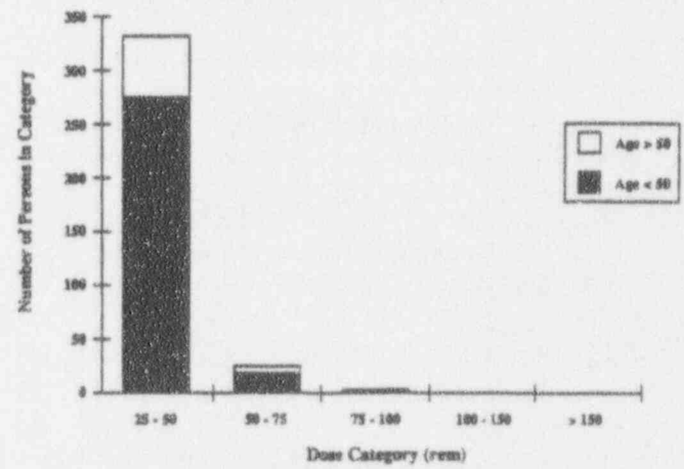

Figure 4.4 Projected Cumulative Site Doses for 1994 Utility and Contractor Personnel (14 Responders)

If these projections are realistic, less than 17 workers younger than 50 would have cumulative doses greater than 50 rem in 1994. Also, no utility or contractor personnel are expected to have a lifetime dose greater than 100 rem. The authors of the EEI report extrapolated this data to the entire nuclear industry "If we assume that the 15 responders represent one-fourth of the industry, we might expect about 600 workers with lifetime doses over 50 rem in 1994, with about one-fourth of them (i.e., 150, probably all contractors) over 75 rem and one-tenth of them (i.e., 60 contractors) over 100 rem."

4.1.6 Effects of Changing the Annual Dose Guidance

The EEI questionnaire asked: "If all utilities adopted Uniform Site Annual Whole Body Dose Equivalent Administrative Limits (or guidance values), set at the following values, what difficulties, additional costs, collective dose increases, and ALARA effects do you see occurring: 4 rem, 3 rem, 2.5 rem, 2 rem, 1 rem, 0.5 rem?" The responses to this question were varied, and complicated by the fact that a similar question was asked: "If NRC lowered the 10 CFR 20 annual committed effective dose equivalent limit to the following values, what do you see occurring: 4, 3, 2.5, 2, 1, 0.5 rem?" The following conclusions were drawn from the responses:

1. None of the seventeen responders felt that an annual dose limit of 4 rem would affect operations significantly. (Ten felt the effect would be minimal; seven said very minor.)

2. According to seven responders, an annual limit of 3 rem is achievable, but the contractor's workforce would have to be expanded.

3. At 2 rem yr^{-1}, two of five responders felt the limit was achievable. One responder felt the limit was possibly achievable, and two felt it would significantly affect operations. An example given was the lack of a qualified labor pool to work outages.

4. At 1 rem yr^{-1}, all responders felt operations would be "...extremely difficult, if not impossible."

4.1.7 Effects of Establishing a Cumulative Dose Limit

The questionnaire asked, "If a cumulative or lifetime effective whole body dose limit were imposed by the NRC, what difficulties, additional costs, collective dose increases, and ALARA effects ... do you see occurring at 3 x age, 2 x age, 1.5 x age, 1 x age and 0.5 x age?" Because many of the 21 responders already had adopted a 1 x age administrative guideline and had experience with its effects, the responses were more consistent than those on other questions about anticipated effects:

1. Most responders felt that minimal impact would occur for utility personnel with a cumulative limit of 3 x age, 2 x age, and 1.5 x age; at a level of 0.5 x age, most saw substantial effects.

2. The majority of responders felt that minimal impact would occur for contractor personnel at 3 x age, and about half felt that there would be minimal impact at 2 x age.

3. At a cumulative limit of 1 x age, 11 responders saw minimal impact on the numbers of utility personnel; the 10 other responders mentioned impacts, such as scheduling problems, lack of critical plant specialists, increased personnel and associated dose for certain jobs, and additional costs, e.g., source term reduction modifications/operations, radiation protection, and salaries.

4. At a cumulative limit of 1 x age, only 1 responder predicted little effect on contractor personnel; 20 responders felt there would be impacts. The same impacts as those listed in 3. would occur, but to a greater degree.

5. At the level of age times 0.5, most responders expected substantial effects on utility personnel and all but two see substantial effects for contractor personnel.

4.2 Department of Energy (DOE) Report

4.2.1 Cost Impact

Based on responses from 37 DOE contractors (~ 60%), the projected costs for all sites combined for a 20 mSv (2 rem) annual limit without a doubling of the neutron quality factor, and with a doubling of the neutron quality factor are as follows:

	Neutron Quality Factor of 10	Neutron Quality Factor of 20
Personnel Costs	$11M	$15M
Modification Costs:		
Initial	$279M	$369M
Annual	$ 3M	$ 4M
Radiation Protection Costs:		
Initial	$ 13M	$ 17M
Annual	$ 5M	$ 7M
Increased Collective Dose	103 person-rem	243 person-rem

As noted in Section 3.1.2, the estimates do not include the Rocky Flats plants and Los Alamos National Laboratory, which have significant neutron exposures and collective doses. In addition, the costs associated with more restrictive Annual Limits on Intakes (ALI) for intakes of radioactive materials and the use of committed effective dose equivalent are not fully represented.

4.2.2 Annual Reported Doses, 1978 to 1988

Figure 4.5 (reproduced from the DOE report) shows a downward trend in the average annual dose equivalent for DOE personnel with measurable exposures from 1985 to 1988.

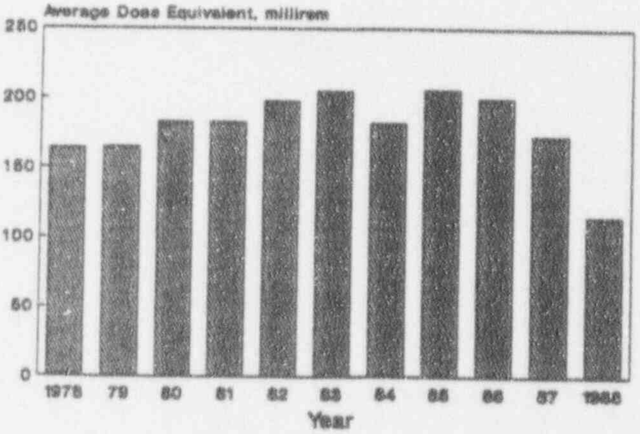

Figure 4.5 Average Annual Dose Equivalent for DOE Workers with Measurable Exposure, 1978-1988

The average dose per worker, with measurable exposure, was typically less than 2 mSv yr^{-1} (200 mrem yr^{-1}), which is well below both the DOE annual limit of 50 mSv yr^{-1} (5 rem yr^{-1}) and the proposed 20 mSv yr^{-1} (2 rem yr^{-1}). The recent decreases are attributable to DOE's continuing ALARA efforts and changes in its mission.

Figure 4.6 (taken from the DOE Report) shows the total number of DOE employees and visitors exceeding 2.0, 1.0, and 0.5 rem annually from 1978 to 1988.

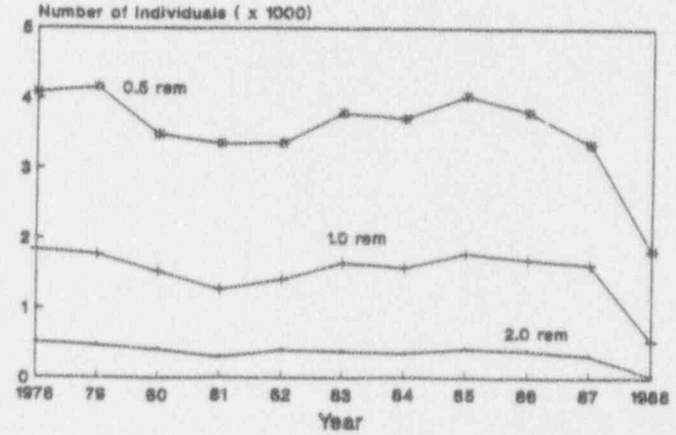

Figure 4.6 Number of DOE Employees and annual dose 1978-1988

In 1988, the total number of DOE personnel and visitors exceeding ~ 2.0, 1.0, and 0.5 rem was 35, 548, and 1,862, respectively. If the decreasing trend in annual doses continues, a very small percentage (< 1%) of DOE workers will exceed 2.0 rem yr^{-1}. Following the survey, the DOE issued its Radiological Control Manual in June 1992, establishing an administrative limit of 2.0 rem yr^{-1}.

4.2.3 Lifetime Cumulative Exposure Limits

The DOE BIER V survey asked the respondents to identify which workers might exceed or come within 10% of exceeding a cumulative lifetime limit of age in years times 1 rem. Respondents also were asked to estimate costs associated with implementing a cumulative dose limit (these data are not typically maintained at DOE contractor facilities).

Facility responses were summarized as follows:

- Few DOE contractor facilities responded to this question, because most did not maintain records on lifetime cumulative exposure; 57 workers were identified as having exceeded or being within 10% of exceeding the lifetime exposure limit.

- The current occupational categories for the 57 workers identified were as follows:

  21% - Managers/Administrators
  14% - Operators (plant/system/utility)
  14% - Engineers
  11% - Science Technicians
  7% - Pipefitters

  The remaining occupational categories represented less than 5% of the total.

- Total costs identified by the respondents for implementing a cumulative lifetime exposure limit of age in years x 1 rem are as follows (rounded to the nearest million):

  Initial costs $1M
  Annual costs $2M

The DOE Radiological Control Manual dated June 1992, established a requirement for a special control level of less than 10 mSv yr^{-1} (1 rem yr^{-1}) when a worker's cumulative lifetime dose exceeds age in years.

4.2.4 Impact on Facility Operations

The DOE BIER V survey asked the respondents to identify those operations at their facility that would have to be discontinued if the proposed limits of 2.0, 1.0, and 0.5 rem were adopted. Two options were to be assumed, the current neutron quality factor (QF), and the proposed doubling of the neutron QF.

The responses from 60% of the DOE facilities (not including Rocky Flats and Los Alamos National Laboratory) are summarized below. We note that this summary does not identify all significant operational impacts.

<u>2.0 Rem Impact on Operations</u>

Respondents identified typically little or no effect, both for the current neutron QF and assuming a neutron QF of 20. Previous internal reviews at Rocky Flats and the Los Alamos National Laboratory, however, identified that plutonium operations would be affected and will require significant modifications at a 2.0 rem limit, coupled with a neutron QF equal to 20.

<u>1.0 Rem Impact on Operations</u>

With the current neutron QF, respondents from one research reactor facility identified the need to operate at a 25 percent reduction in power level.

Assuming a neutron QF of 20, the following additional operations would be discontinued:

- A heat source program and radiography operations at one facility.

- Plutonium metal production at one facility.

<u>0.5 Rem Impact on Operations</u>

The impact of the proposed 0.5 rem on operations was severe, both with the current neutron QF and assuming a neutron QF of 20. Specific operations that would be discontinued or require a change in mission, in addition to the above, include the following:

- Overall fuel and high-level waste processing operations - several respondents identified the need to construct new facilities, with extensive use of robots, to continue processing fuel and to carry out high-level waste operations.

- Respondents from one research reactor identified the need to operate at a 50% reduction in power level.

- The sampling, retrieval, and recovery of transuranic waste would be discontinued at one facility.

- Plutonium scrap recovery would be discontinued at one facility.

- A calorimetry program would be discontinued at one facility.

4.3 Selected 1990 Data from NRC REIRS

Table 4.1 gives the annual exposure data for 6 licensee categories for 1990. Additional data for 1989 are given for industrial radiographers in Table 4.2, for fuel fabricators in Table 4.3, for manufacturers and distributors in Table 4.4, and for nuclear power reactors in Table 4.5. A similar set of tables is provided for 1991.

The 1989 data gives a better measure of "verification" of the survey results while the 1991 data is provided to reflect any change in the dose distributions.

Table 4.1 Annual Exposure Data* 1990

License Category	Number of Licensees Reporting	Number of Monitored Individuals	Number of Workers with Measurable Doses	Collective Dose (person-rems or person-cSv)	Average Individual Dose (rems or cSv)	Average Measurable Dose per Worker (rems or cSv)
Industrial Radiography	258	6,523	4,458	2,120	0.33	0.48
Manufacturing and Distribution	55	4,195	2,345	770	0.17	0.33
Low-Level Waste Disposal	2	925	119	35	0.04	0.29
Independent Spent Fuel Storage	2	190	102	33	0.17	0.33
Fuel Fabrication and Processing	10	13,756	3,233	287	0.02	0.09
Commercial Light Water Reactors***	116	189,254**	100,104**	36,607	0.19	0.37
Totals	443	214,568**	110,204**	39,739	0.19	0.36

* Taken from Table 3.1 from NRC NUREG 0713 Vol 12 (Raddatz and Hagemeyer, 1993).

** These figures are adjusted to account for the multiple counting of transient reactor workers.

*** Includes all LWRs that reported, although all may not have been in commercial operation for a full year, and excludes the gas-cooled reactor.

Table 4.2 Annual Exposure Information for Industrial Radiographers* 1989

Type of Licenses	Number of Licenses	Number of Monitored Individuals	Workers with Measurable Doses	Collective Dose (person-rems or person-cSv)	Average Measurable Dose (rems or cSv)
Single location	66	832	304	41	0.13
Multiple locations	192	5,691	4,154	2,079	0.50
Total	258	6,523	4,458	2,120	0.48

* Taken from Table 3.4 of NRC NUREG 0713 Vol 12 (Raddatz and Hagemeyer, 1993).

Table 4.3 Annual Exposure Information for Fuel Fabricators* 1989

Type of License	Number of Licenses	Number of Monitored Individuals	Workers with Measurable Doses	Collective Dose (person-rems or person-cSv)	Average Measurable dose (rems or cSv)
Uranium Fuel Fab	8	11,583	2,992	243	0.08

* Taken from Table 3.6 of NRC NUREG 0713 Vol 12 (Raddatz and Hagemeyer, 1993).

Table 4.4 Annual Exposure Information for Manufacturers and Distributors* 1989

Type of Licenses	Number of Licenses	Number of Monitored Individuals	Workers with Measurable Doses	Collective Dose (person-rems or person-cSv)	Average Measurable Dose (rems or cSv)
M & D-"A"-Broad	10	3,091	1,862	6551	0.35
M & D-Limited	45	1104	410	38	0.09
Total	55	4,195	2,272	693	0.31

* Taken from Table 3.5 of NRC Report 0713 Vol 12 (Raddatz and Hagemeyer, 1993).

Table 4.5 Summary of Annual Whole Body Distributions By Year and Reactor Type 1989

Reactor Type	Number of Individuals with Whole Body Doses in the Ranges (rems or cSv)											Total Number Moni-tored	Number With Meas. Ex-posure	Total Col-lective Dose
	Not Meas-urable	Meas. <0.10	0.10-0.25	0.25-0.50	0.50-0.75	0.75-1.0	1.0-2.0	2.0-3.0	3.0-4.0	4.0-5.0	5-12.0			
BWRs	39,102	17,210	7,336	5,992	3,717	2,493	4,162	625	41	1		80,679	41,577	15,780
PWRs	54,572	29,791	13,030	10,747	5,759	3,384	4,712	607	43	-		122,645	68,073	20,812
Total	93,674	47,001	20,366	16,739	9,476	5,877	8,874	1,232	84	1		203,324	109,650	36,592

* Adopted from Appendix F of NRC NUREG 0713 Vol 12 (Raddatz and Hagemeyer, 1993).

4.4 Information Obtained from the 1984 EPA Report

4.4.1 Male and Female Workers in the Nuclear Industry

The EPA report (EPA, 1984) shows that the number of male and female workers employed in radiation related work are roughly the same, about 600,000 women and slightly over 700,000 men. Figures 4.7 and 4.8 give the proportion of all male and female workers in various sectors, medicine, industry, the nuclear fuel cycle, government, and miscellaneous fields, including those in nuclear power operations. The data have been separated into male and female subgroups because of the different kinds of activities that they pursue.

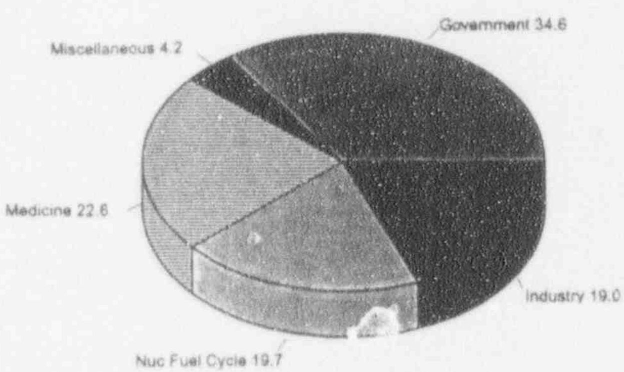

Figure 4.7 Percent of Male Radiation Workers in Various Sectors

Figures 4.7 and 4.8 show that males and females carrying out very different kinds of tasks. Most female radiation workers are employed in medicine and dentistry, whereas the male radiation workers are fairly evenly split among all the various sectors, with industry being the largest. Further analysis indicated that the males employed in medicine are performing different functions than the females.

It also is noteworthy that the mean age of all male radiation workers is slightly higher (36 years) than that for females (31 years).

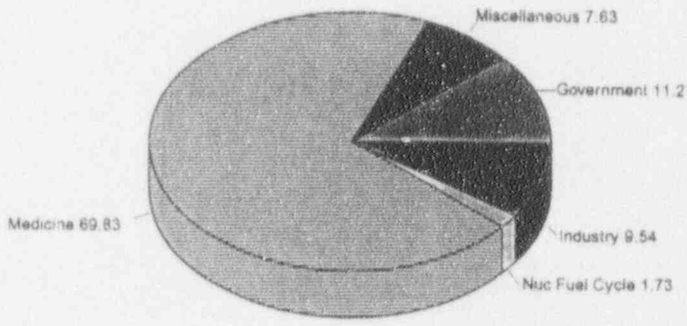

Figure 4.8 Percent of Female Radiation Workers in Various Sectors

4.4.2 Correlation of Radiation Dose with Age

Two of the dose limit options include lifetime limits on dose. This approach has been questioned because some experts feel that the older radiation workers (age 40 or older), because of their greater experience, may be required for tasks which expose them to high doses. This would imply that the older workers would have had higher annual doses.

To assess this view, we checked for a correlation between age and radiation dose for occupational workers. The age group data given in the EPA report (EPA, 1984) were transformed to mean ages for each group and compared with the mean annual dose to each group. The data were weighted by the number of workers in each group. Table 4.6 shows the mean annual dose equivalent for all U. S. radiation workers by sex and age.

4.4.3 Males

In Table 4.6, the relationship between age and mean annual exposure indicates that males aged 22 to 42 had the higher exposures. For those aged 42 to 67 there is a downward trend of exposure with age.

4.4.4 Females

Table 4.6 shows a somewhat different picture. As women radiation workers grow older they seem to receive more radiation, although the mean annual dose is low compared with males of all ages. As shown in Figure 4.8, the majority of female radiation workers are employed in the medicine and dentistry, which probably accounts for the mean annual dose for women being about 60 mrem in contrast to the significantly higher mean annual dose for men, who work primarily in industry (Figure 4.7).

Table 4.6 Mean Annual Dose Equivalent for U.S. Radiation Worker

	Males		Females	
Age	Mean Annual Dose (mrem)	Number of Workers	Mean Annual Dose (mrem)	Number of Workers
19	100	8,035	40	25,090
22	210	84,336	50	168,534
27	180	147,742	50	158,986
32	160	157,869	60	94,237
27	160	104,636	60	57,865
42	170	69,220	60	38,649
47	150	52,934	60	24,760
52	130	39,650	60	17,608
57	130	30,781	60	12,360
62	100	14,489	50	5,389
67	90	5,958	60	1,485

5 Questionnaire Results Obtained in this Survey

The data given here should be taken as an indication of the issues. A small number of responses was received from each industry. As noted in Section 3.2.3., the validity of the conclusions of the report depend on the working groups' detailed evaluation, for which the responses to the questionnaire provided a framework. The responses and the data given by the working committee are presented by practice or industry type, and are summarized for each in two tables.

The first table, for each industry class, gives information on impacts, and the second on exposure experience. In addition, all comments from the questionnaire or from the members of the working party are given.

5.1 Medical/Dental and Veterinary Practice

There were 20 responses from medical institutions and one from veterinary practice.

Table 5.1 Impacts on Medical/Dental and Veterinary Practice

	Possible Dose Limit			
Impacts	2 rem y^{-1}	1 rem y^{-1}	5 rem y^{-1} age in rem	2 rem y^{-1} age in rem
Collective dose:				
No Change	17	15	19	19
Increase	-	2	-	-
% Increase	3	3	1	1
Facility Modification:				
None required	13	8	19	14
Modifications required	7	11	-	3
Costs (individual responses)	\$2K to \$150K	\$4K to \$300K	-	\$24K to \$100K
Radiation Protection Cost:				
No increase	11	8	19	12
Will increase	9	11	-	6
Cost/yr (individual responses)	\$3K to \$100K	\$1K to \$100K	-	\$16K to \$100K

Table 5.2 1989 Exposure Experience

Number of Employees with Annual Doses:

>5 rem 11 >2 rem 14 >1 rem 47

Number of Employees with Lifetime Dose Greater Than Age in Rem: 3

Number of Employees with Measurable Dose: 4370

Annual Collective Dose: 613 rem

Medical/Dental and Veterinary Practice Comments

1. Our cardiac catheterization and angiography areas are the biggest person-rem inflator. All recommended shield/safeguards are in place, but with patient volume, exposures are still high. Limiting annual doses to 1-2 rem would be unattainable.

2. This is a cardiac catheterization lab and reported dose is outside the apron. Facility modifications may not be possible and very much depends on the willingness of the cardiologist.

3. Bad idea to require D < current. Means increased therapy room shielding at no benefit. Waste of patient resources and care.

4. Film readings outside the apron. Six cardiologists will require $8,000 in ceiling-suspended shielding in 3 cath labs just to keep the badge readings down. This dose limit is not justified.

5. There is an urgent need for guidance on computation of effective dose equivalent.

6. This change will be of no impact in the medical field.

7. Why bother unless there is clear evidence of harm at annual doses less than 5 rem? RERF database is hardly applicable to medical workers.

8. The 1 rem yr^{-1} limit might have some problems for radiologists/cardiologists performing fluoroscopy on collar badge readings. These groups are provided with two dosimeters.

9. In the design of medical facility, there would be a significant increase in construction costs and essentially no benefit to patients or personnel. Must consider badge position.

10. Data are whole-body exposure, when two badges worn, data for that worn under Pb apron used.

11. Increase in Radiation Protection cost for purchase of additional lead glasses and thyroid shields and possible use of double badging for specific groups of workers.

12. Current dose limits are ambiguous when applied to a diagnostic radiology department since the film badge measurement dose is typically 5 to 10 times the EDE due to apron, glasses, etc.

13. Although our actual exposures are low, a change in the "general public" levels would require modifications at our vaults. The expense would be nontrivial and the benefit would be trivial. I don't believe any of the current evidence warrants changing the current limits.

14. Above are whole-body doses only. If "head and neck" dose limits is reduced to 1 rem yr^{-1} our cardiology physicians would have to limit the number of cardiac cath cases.

15. Might as well do away with < age. 1 rem too low for special procedures.

16. The data showing 11 people over 5 rem yr^{-1} and 14 over 2 rem from 20 sources may be lower than the real numbers. In my experience, a significant number of personnel using fluoroscopy do not wear the dosimeter that is provided.

17. Let's set a 10 mSv annual BRC/de minimum dose as soon as possible, so we can focus efforts on the real health hazards of radiation and stop wasting time, money, and personal efforts on trivia.

18. Personnel dosimetry data reported by medical institutions for radiation producing devices personnel, such as cardiologist, invasive radiologist, etc., should be viewed with some suspicion as these individuals may be badged at more than one institution and may fail to properly use such devices.

19. How much reduction in personnel exposure can be realized by proper radiation safety instructions furnished to non-radiology personnel is difficult to asses. How much radiation safety instructions are furnished to physicians, nurses, operating room personnel, etc., outside the radiology departments is variable. Additionally, application of these instructions to properly reduce exposure is also variable. Uniform instructions and operational application of proper technique might reduce exposure at very little additional cost.

20. With regard to the frequently reported partial-body exposures to personnel performing medical procedures, there exists a need for guidance as to the proper assessment to a whole-body dose equivalent. Without such equivalency, the "outside the apron" dose is discounted as insignificant or overstated as impossible to do anything about.

5.2 Nuclear Power Reactors

There were seventeen responses from nuclear power stations.

Table 5.3 Impacts in Nuclear Power Reactors

	Possible Dose Limit			
Impacts	**2 rem y^{-1}**	**1 rem y^{-1}**	**5 rem y^{-1} age in rem**	**2 rem y^{-1} age in rem**
Collective dose:				
No change	6	1	17	6
Increase	10	15	-	11
Decrease	1	1	-	-
% Increase	2 to 20	5 to 30	-	2 to 20
Facility Modifications:				
None required	9	3	16	9
Modifications required	8	14	1	7
Costs (individual responses)	$25K to $10M	$25K to $50M	$25K	$50K to $10M
Radiation Protection Cost:				
No increase	8	1	16	7
Will increase	9	16	1	10
Costs/yr (individual responses)	$5K to $.5M	$5K to $1M	$100K	$5K to $750K

Table 5.4 1989 Exposure Experience

Number of Employees with Annual Doses:
>5 rem 0   >2 rem 331   >1 rem 3,101
Number of Employees with Lifetime Dose Greater Than Age in Rem: 178
Number of Employees with Measurable Dose: 24,098
Annual Collective Dose: 10,915

Nuclear Power Reactor Comments

1. Two rem yr^{-1} is a challenge but achievable with management support. 1 rem yr^{-1} will require major modifications and increase in personnel (especially for older facilities >15 years).

2. LWR's will not be able to operate with a 1 rem yr^{-1} limit.

3. Facility modifications should not be necessary; specialized tasks or maintenance evolutions may result in higher doses for a few individuals (i.e., 10-15), more frequent TLD processing may be required, outage contractors may be unavailable for work due to dose restrictions.

4. A limit of cumulative < age, 3 rem yr^{-1} not to exceed 10 rem in 5 years is workable. We need flexibility.

5. We are attempting to limit HP Techs to <1 rem for 1990; it could have been done in 1989. A few (contractor) employees have > rem than years may be put out of work. Initial approach to ≤ 1 rem yr^{-1} will probably be to hire more people.

6. Costs are extremely difficult to assess.

7. The nuclear power facilities have not provided an informed, representative response to the questionnaire.

8. We recognize that the current regulatory limits do not provide a total lifetime dose limitation other than the defacto limit of 5 rem yr^{-1} and, therefore, theoretically allows significant lifetime dose. If the regulatory limits need updating, the annual dose limits should not be changed, and a lifetime dose limit should be instituted equivalent to the NCRP recommendation of age = rem, with the proviso that persons who have already exceeded this limit be provided a special annual limit of 1-2 rem.

9. The use of administrative dose limits established below regulatory dose limits should be considered

10. Two rem yr^{-1} limit would be difficult and costly, but achievable for utility workers. However, for contract personnel it would be very difficult and exceedingly costly.

11. For those individuals who would exceed the lifetime limit of age in rem, a 2 rem yr^{-1} limit would be necessary in order to maintain their employment within the industry.

12. The number of the more highly exposed contractor staff working our outages ranges from 50-100, each receiving 1-2 rem per outage. Since the contractor staff works up to four to five outages per year, each of the more highly exposed workers becomes restricted by year's end under the current administrative dose limits of approximately 4 rem yr^{-1}. [Note that most of the contractor staff do not have a "high" lifetime dose (e.g., 0.2-0.5 x age in rem), as their employment

has not always been in the higher dose work activities.]

13. If lower regulatory dose limits were instituted, the contractor companies would be forced to hire more "temporary" staff, perform more training, charge higher rates, and, as a result, increase the financial cost. More importantly, this would result in increased collective dose due to using a larger and less skilled workforce. Likewise, we would incur an increase in our company Health Physics and support staff's dose since we would be supporting a larger, less skilled radiation worker force. In addition, the use of more "temporary, less skilled" workers also increased the probability of personnel error, which is a decrease in nuclear safety for both the co-workers and the general public.

14. In the process of setting new regulatory dose limits, it is important to understand the dose limitation system typically in use at nuclear facilities restricts actual doses to approximately 80 percent of the regulatory limits; i.e., "administrative limits" are set by the utilities well below the "regulatory limits." The use of administrative dose limits provides a "safety margin" designed to help the worker avoid exceeding regulatory limits. If the NRC regulatory limit were 2 rem yr^{-1}, nuclear facilities would essentially be required to set administrative limits in the range of 1.5 rem yr^{-1}.

15. In addition to regulatory and administrative dose limits, the nuclear industry has achieved successes in steadily reducing individual, collective, and lifetime accumulated dose to As Low As Reasonably Achievable (ALARA). In light of the entire system of dose limitation and ALARA practices, we believe current annual dose limits under the revised 10 CFR 20 provide appropriate and adequate worker protection. In addition, an ALARA cost/benefit analysis has not been performed, which indicates that reductions in the individual's annual dose justify the expected increase in collective dose.

16. If reduced dose limits must be instituted, we believe that the important parameter to control should be lifetime dose, not annual dose. A modified lifetime limit similar to the National Council on Radiation Protection and Measurements' (NCRP's) recommendation would be appropriate. The modification would be to allow a 1-2 rem yr^{-1} provision for persons who are approaching or have already exceeded this limit. We believe that the International Commission on Radiological Protection (ICRP) recommendation of 10 rem in five years, with a yearly limit of 5 rem, would unnecessarily restrict our operational flexibility.

17. It is noted that the dose risk models of BEIR-V do not make a distinction between the risk for chronic exposures based on annual dose rates which vary from 2-5 rem yr^{-1}, i.e., risk associated with chronic exposure is primarily a function of total dose. Therefore, risk associated with current regulatory dose limits could be reduced by use of the NCRP recommendation for lifetime dose with a 5 rem yr^{-1} cap, while simultaneously allowing us the operational flexibility necessary to operate efficiently.

18. Provision should be made to permit exposures in excess of the limits, i.e. special planned exposures. This may be particularly true if NRC mandated backfits occur.

19. With an annual limit of 2 rem or less, some safety related inspections might have to be curtailed.

5.3 Nuclear Power Reactor Contractors

There were three responses from power reactor contractors.

Table 5.5 Impacts in Nuclear Power Reactor Contractors

	Possible Dose Limit			
Impacts	**2 rem y^{-1}**	**1 rem y^{-1}**	**5 rem y^{-1} age in rem**	**2 rem y^{-1} age in rem**
Collective dose:				
No change	1	-	3	2
Increase	2	3	-	1
Decrease	-	-	-	-
% Increase	50 and 100	50 to 1000	-	100
Facility Modifications:				
None required	1	1	2	2
Modifications required	1	1	1	1
Costs (individual responses)	up to $50M	$100M	$1M	$20-50M
Radiation Protection Cost:				
No Increase	-	-	3	2
Will Increase	2	2	-	1
Costs/yr (individual responses)	$.2M and $10M	$.3M and $25M	-	$10M

Table 5.6 1989 Exposure Experience

Number of Employees with Annual Doses:		
>5 rem 1	>2 rem 448	>1 rem 1,871
Number of Employees with Lifetime Dose Greater Than Age in Rem: 56		
Number of Employees with Measurable Dose: 5,292		
Annual Collective Dose: 1,718		

Nuclear Power Reactor Contractors Comments

1. The dose limits in the new 10 CFR 20 we are prepared to meet. Dose limits on the order of 1 rem yr^{-1} per person would be catastrophic. AIF study 10 years ago showed this.

2. Only 5-10 members of the work force annually accumulate exposures greater than 1 rem. They are the most skilled and efficient. If limited, the collective dose will increase.

3. The general population is young and usually change jobs in 5-7 years, thereby not accumulating a large lifetime dose.

4. Can meet a 100 rem/lifetime plus a "grandfather clause" with 5 rem yr^{-1} limit.

5. A "grandfather clause" would be necessary if a lifetime limit is adopted.

6. Utilities that perform their own outage maintenance will have many of the same difficulties as the contractors.

5.4 Test and Measurements Including Industrial Radiography

There were nine responses from test and measurement groups.

Table 5.7 Impacts in Test and Measurements Including Industrial Radiography

	Possible Dose Limit			
Impacts	**2 rem y^{-1}**	**1 rem y^{-1}**	**5 rem y^{-1} age in rem**	**2 rem y^{-1} age in rem**
Collective dose:				
No change	8	5	9	8
Increase	1	1	-	1
Decrease	-	2	-	-
% Increase	-	20	-	-
Facility Modifications:				
None required	9	7	9	9
Modifications required	-	2	-	-
Costs (individual responses)	-	$20K to $400K	-	-
Radiation Protection Cost:				
No increase	6	3	9	5
Will increase	3	3	-	1
Cost/yr (individual responses)	$15K to $25K	$30K to $50K	-	$25K

Table 5.8 1989 Exposure Experience

Number of Employees with Annual Doses:
>5 rem 0   >2 rem 10   >1 rem 21
Number of Employees with Lifetime Dose Greater Than Age in Rem: 0
Number of Employees with Measurable Dose: 285
Annual Collective Dose: 109

Tests and Measurements Comments

1. We have large NDT x-ray facilities, but radiation protection practices effectively limit the monthly dose to 25 to 50 mrem.

5.5 Universities

There were four responses from universities.

Table 5.9 Impacts in Universities

	Possible Dose Limit			
Impacts	2 rem y^{-1}	1 rem y^{-1}	5 rem y^{-1} age in rem	2 rem y^{-1} age in rem
Collective dose:				
No change	4	4	4	4
Increase	-	-	-	-
Decrease	-	-	-	-
Facilities Modifications:				
None required	4	3	4	4
Modifications required	-	1	-	-
Costs (individual responses)	-	$80K	-	-
Radiation Protection Cost:				
No increase	3	3	4	4
Will increase	1	1	-	-
Costs yr (individual responses)	$80K	$80K	-	-

Table 5.10 1989 Exposure Experience

Number of Employees with Annual Doses:

>5 rem 0   >2 rem 1-2   >1 rem 3-4

Number of Employees with Lifetime Dose Greater Than Age in Rem: 0

Number of Employees with Measurable Dose: 850

Annual Collective Dose: 255

Universities Comments

1. The kinds of activities carried out in this university environment should not weigh heavily in setting dose limits for high hazard work environments.

5.6 Manufacturing and Distribution, Including Cyclotron Produced Radiopharmaceuticals

There were five responses from this group.

Table 5.11 Impacts in Manufacturing and Distribution

	Possible Dose Limit			
Impacts	**2 rem y^{-1}**	**1 rem y^{-1}**	**5 rem y^{-1} age in rem**	**2 rem y^{-1} age in rem**
Collective dose:				
No change	4	1	3	1
Increase	1	4	-	1
Decrease	-	-	-	-
% Increase	13	18-25	-	13
Facility Modifications:				
None required	2	-	3	2
Modifications required	3	5	-	1
Costs (individual responses)	$25K-$100K	$10K-$1M	-	$60K
Radiation Protection Cost:				
No increase	3	-	4*	2
Will increase	2	5	-	2
Cost/yr (individual responses)	$30K to $60K	$10K to $60K	-	-

* 3-no increase, 1-not sure

Table 5.12 1989 Exposure Experience

Number of Employees with Annual Doses:
>5 rem 0   >2 rem 20   >1 rem 72
Number of Employees with Lifetime Dose Greater Than Age in Rem: 6
Number of Employees with Measurable Dose: 117
Annual Collective Dose: 86

Manufacturing and Distribution Comments

1. 1 or 2 rem yr^{-1} will almost certainly increase the cost of radiopharmaceuticals produced in cyclotrons such as this facility.

2. Special exposure limits may be needed for workers who produce isotopes with cyclotrons.

3. We have several people with >50% extremity limit. If extremities are lowered by 2/5 as above, then we would have large expenses, ~$50,000 for equipment.

4. At a recent accelerator meeting, the subject of the economic effect of a 2 rem yr^{-1} dose limit was informally discussed. The consensus was that positive ion cyclotrons, now commonly used, will not be economically feasible for radiopharmaceutical production with a 2 rem yr^{-1} limit. Manufacturers are assuming that this limit will be in effect within several years and all new production machines will almost certainly be negative ion. The approximate cost of a negative ion machine is about $5M, and there is a company than can convert the Cyclotron Corporation CS-30, a common production machine, to negative ion for a reported $2.5M. I would expect 2 or 3 replacements and an equal number of conversions (if this proves feasible).

5.7 Waste Management

There were three responses, two from U.S. operators, the other from an operator outside the country; the latter indicated with an asterisk.

Table 5.13 Impacts in Waste Management

	Possible Dose Limit			
Impacts	**2 rem y^{-1}**	**1 rem y^{-1}**	**5 rem y^{-1} age in rem**	**2 rem y^{-1} age in rem**
Collective dose:				
No change	2	1	2	2
Increase	1*	1	-	-
Decrease	-	1*	1*	1*
% Increase	-	10	-	-
Facility Modifications:				
None required	1	1	2	1
Modifications Required	2*	2*	1*	2*
Costs (individual responses)	-	-	-	-
Radiation Protection Cost:				
No increase	-	-	2	-
Will increase	3	3	1*	3
Cost/yr (individual responses)	$5K to $1.2M*	$10K to $1.2M*	$1.2M*	$1.2M*

* non-U.S.

Table 5.14 1989 Exposure Experience

Number of Employees with Annual Doses:

>5 rem 0   >2 rem 7   >1 rem 24

Number of Employees with Lifetime Dose Greater Than Age in Rem: 0

Number of Employees with Measurable Dose: 142

Annual Collective Dose: 77.3

<u>Waste Management Comments</u>

1. Radioactive waste management is generally changing from shallow land burial to engineered-at-grade disposal. Because of this basic change, we have used a design goal that the average radiation worker should not exceed 500 mrem yr^{-1}.

2. These totals do not include exposure associated with waste processing services provided at generator locations.

5.8 Fuel Fabrication, UF_6 Production

There were two responses in this category.

Table 5.15 Impacts in Fuel Fabrication, UF_6 Production

	Possible Dose Limit			
Impacts	2 rem y^{-1}	1 rem y^{-1}	5 rem yr^{-1} age in rem	2 rem yr^{-1} age in rem
Collective Dose:				
No change	1	1	1	1
Increase	-	-	-	-
Decrease	-	-	-	-
% Increase	-	-	-	-
Facility Modification:				
None required	1	1	1	1
Modifications required	1	1	-	-
Cost (individual responses)	\$3.75M	\$6.25M	-	-
Radiation Protection Cost:				
No increase	1	1	-	-
Will increase	1	1	-	-
Cost/yr (individual responses)	\$.45M	\$.7M	-	-

Table 5.16 1989 Exposure Experience

Number of Employees with Annual Doses:

>5 rem 0 >2 rem 91 >1 rem 96

Number of Employees with Lifetime Dose Greater Than Age in Rem: 75

Number of Employees with Measurable Dose: 817

Annual Collective Dose: 545

Fuel Fabrication Comments

1. We are concerned that any reduction in the occupational dose may be a lever to lower the already ultra-conservative public dose limits - to what benefit?

2. The addition of external and internal exposure will increase these doses by a factor of ~10

5.9 Well Logging

These data came primarily from a member of the working group on the basis of a personal survey. One additional response to the questionnaire is included. The data are for 1988.

Table 5.17 Impacts in Well Logging

	Possible Dose Limit			
Estimated Impacts	**2 rem y^{-1}**	**1 rem y^{-1}**	**5 rem y^{-1} age in rem**	**2 rem y^{-1} age in rem**
Collective dose:				
No change	2	2	2	2
Increase	-	-	-	-
Decrease	-	-	-	-
Facility Modifications:				
None required	2	2	2	2
Modifications required	-	-	-	-
Cost (individual responses)	-	-	-	-
Radiation Protection Cost:				
No increase	2	2	2	2
Will increase	-	-	-	-
Cost/yr (individual responses)	-	-	-	-

Table 5.18 1989 Exposure Experience

Number of Employees with Annual Doses:

>5 rem 4 >2 rem 9 >1 rem 193

Number of Employees with Lifetime Dose Greater Than Age in Rem: 0

Number of Employees with Measurable Dose: 3,378

Annual Collective Dose: -

Well logging Comments

1. Approximately a third of the dose received by well loggers is from neutrons (QF=5). Few well logging technicians are over 40 years of age and the average tenure of a technician is about 10 years. Therefore, the 5 rem yr^{-1} and lifetime would seem to be achievable, although more data are needed.

5.10 Others (R&D, Regulatory)

There are two responses included in this section. Although they have little in common, the impacts are quite similar, so a single presentation is considered acceptable.

Table 5.19 Impacts in Others (R&D, Regulatory)

	Possible Dose Limit			
Impacts	**2 rem y^{-1}**	**1 rem y^{-1}**	**5 rem y^{-1} age in rem**	**2 rem y^{-1} age in rem**
Collective dose:				
No change	2	2	2	2
Increase	-	-	-	-
Decrease	-	-	-	-
Facility Modifications:				
None required	2	2	2	2
Modifications required	-	-	-	-
Cost (individual responses)	-	-	-	-
Radiation Protection Cost:				
No increase	2	2	2	2
Will increase	-	-	-	-
Cost/yr (individual responses)	-	-	-	-

Table 5.20 1989 exposure experience

Number of Employees with Annual Doses:

>5 rem __0__ >2 rem __0__ >1 rem __0__

Number of Employees with Lifetime Dose Greater Than Age in Rem: __0__

Number of Employees with Measurable Dose: __33__

Annual Collective Dose: __2 rem__

6 High Dose Groups Within an Industry

6.1 Introduction

The data given in the tables in Section 5 do not reveal the potential impacts of lowered doses to selected categories of workers receiving higher annual doses than the average. Some indications of the importance of this issue appear in the comments of Section 5, particularly for the medical and nuclear-power communities. In medicine, particularly cardiology, angiography, and interventional radiology, reduction of dose limits might impact the availability of specialized medical attention.

6.2 NRC-Sponsored Study on High Dose Group Workers

In 1989, the NRC sponsored a BNL study of the distribution of dose as a function of special work groups in the nuclear-power industry (Khan et al., 1991a). Information was obtained from responses to a questionnaire addressing the following:

a). What proportion of workers were getting higher than average dose;

b). What was the magnitude of these doses;

c). Are there any special, highly skilled work groups that are chronically getting the higher doses;

d). Is there a shortage of skilled workers who are receiving higher than average doses?

Twenty-two nuclear power sites and six nuclear power contractor organizations responded. Among the power plant organizations responding, thirteen were pressurized water reactor (PWR) sites and nine were boiling water reactor (BWR) sites.

Table 6.1 shows the whole-body dose data for one year for the PWR plants in this group; Table 6.2 shows the data for BWR plants. The data cover the total number of persons monitored at the plant, including contractors.

Table 6.1 Whole-Body Dose Data for PWR Plants for 1988

Plant (units)	Total Number monitored	Number of Persons with Annual Whole-Body Dose				Average Dose Per worker (rem)
		> 1 rem		> 2 rem		
		Persons	%	Persons	%	
PW1 (3)	3,841	237	6.2	24	0.6	0.11
PW2 (2)	4,446	606	13.6	164	3.7	0.24
PW3 (2)	2,234	8	0.4	0	0	0.06
PW4 (1)	2,519	53	2.1	2	0.1	0.26
PW5 (2)	2,943	93	3.2	6	0.2	0.19
PW6 (2)	759	-	-	0	0	0.10
PW7 (2)	3,290	481	14.6	80	2.4	0.33
PW8 (3)	374	166	4.4	10	0.3	0.11
PW9 (2)	1,446	76	5.3	5	0.3	0.32
PW10 (1)	1,975	272	13.8	60	3.0	0.50
PW12 (1)	1,984	18	0.9	18	0.9	0.23
PW13 (1)	1,279	28	2.2	1	0.1	0.21

Table 6.2 Whole-Body Dose Data for BWR Plants for 1988

Plant (units)	Total Numbered Monitored	Number of Persons with Annual Whole-Body Dose				Average Dose per worker (rem)
		> 1 rem		> 2 rem		
		Persons	%	Persons	%	
BW1 (2)	1.684	28	1.7	5	0.3	0.33
BW3 (1)	4,887	68	1.4	7	0.1	0.19
BW4 (1)	2,265	302	13.3	63	2.8	0.51
BW5 (2)	2,616	316	12.1	22	0.8	0.28
BW6 (2)	3,957	1,073	27.1	326	8.2	0.45
BW7 (2)	3,727	569	15.3	69	1.9	0.29
BW8 (3)	10,322	862	8.4	201	1.9	0.28
BW9 (1)	3,215	612	19	148	4.6	0.52

Both tables show that the average dose per worker is only a small fraction of the present annual whole-body dose limit. In addition, only a small percentage of workers (from 0.1 to 8%) are getting doses greater than 20 mSv (2 rem) annually.

The PWR data for 1988 (Table 6.3) show that workers had annual doses above 20 mSv, and 76 have lifetime doses (in rem) greater than their age. Such workers are maintenance technicians, welders, riggers, millwrights, and assorted contract personnel. Most of the 76 persons from the high-dose groups in the dose greater than age category were maintenance technicians and other contract personnel.

Table 6.3 Whole-Body Dose Data for Various Worker Groups at PWR Plants for 1988

Work Group	Number with dose		
	Annual		Lifetime
	>1 rem	>2 rem	>age
Maintenance Techs	178	23	20
Boiler Makers	26	5	2
Welders	119	24	0
Health Physics Techs	127	10	6
Pipe fitters	75	11	0
Riggers	255	61	5
Millwrights	237	49	2
Fuel Handlers	39	11	0
Decon Workers	36	7	0
Other Contract Personnel	181	85	41
Total	1,273	286	76

Table 6.4 Whole-Body Dose Data for Various Worker Groups at BWR Plants for 1988

Work Group	Number with Dose		
	Annual		Lifetime
	> 1 rem	> 2 rem	> age
Pipe fitters	83	23	0
Health Physics Techs	188	8	7
Millwrights	1,154	418	1
Boiler Makers	15	2	0
Riggers	19	1	0
Maintenance Techs	277	18	54
I & C Techs	85	13	0
Quality Assurance	28	2	2
Radwaste Handlers	18	3	1
Other Contract Personnel	277	100	2
Total	2,144	588	67

For BWRs (Table 6.4). 588 workers are getting annual doses above 20 mSv. However, the number of persons whose lifetime dose is greater than their age is less than for PWRs, 67 workers. Almost all workers getting doses greater than 20 mSv yr^{-1} are in two groups, millwrights and other contract personnel. The preponderant proportion of the 67 persons with lifetime dose greater than age are maintenance technicians.

6.2.1 Analysis of Dose Data Obtained in the Study

Table 6.1 shows that for some PWRs nearly 15% of the persons monitored are likely to receive > 1 rem yr^{-1}. Because the number monitored implies anyone who is issued a radiation badge, and therefore, typically includes all visitors, engineering, and management personnel, the number with annual dose greater than 1 rem as a proportion of the actual radiation workforce is likely to be even higher than 15%. Table 6.2 shows the proportion of persons getting annual doses greater than 1 rem, which may range up to 27% for BWR plants. Contract personnel are included in these sets of numbers for the two plant types. However, the data do not reflect the total doses to transient workers getting dose at several sites.

Correlations with other factors were made for plants listed in Tables 6.1 and 6.2 in which more than 10% of the workers had doses greater than 1 rem yr^{-1}. We found no correlations with power rating, vendor, multiple vs. single plant sites, utilities with several plants vs. those with one or two nuclear units, and the date the plant went into service.

Only three PWR plants and three BWR plants reported that more than 2% of people were getting doses above 2 rem yr^{-1}. Again, since this value is based on all who were issued a radiation badge, the number with dose greater than 2 rem yr^{-1} as a proportion of the actual radiation workforce will be greater. Every plant reported an average dose per worker of less than 0.5 rem yr^{-1}.

6.2.1.1 Pressurized Water Reactor Data

Typically, between 100-200 people per reactor unit at PWR plants had doses above 1 rem yr^{-1} is. However, PWR2 (Table 6.1) with 2 units reported over 300 persons per unit with doses above 1 rem yr^{-1}. The number of health physics technicians and maintenance technicians with doses above 1 rem yr^{-1} per plant are generally in double digits. The same is true for welders, millwrights, and riggers, except for 2 sites with more than 100 people getting doses above 1 rem yr^{-1}.

Compared to 1 rem yr^{-1}, there is a five-fold decrease in the total number of persons getting doses above 2 rem yr^{-1}. This is also reflected in the doses to individual work groups. The number of workers in any work group having more than 2 rem yr^{-1} is appreciably less than the number of workers with more than 1 rem yr^{-1}. The number with lifetime dose greater than age is a further factor of 4 lower than the number with annual dose above 2 rem.

The average dose to each work group is generally less than 1 rem yr^{-1}, except at PWR 7 with two units, where boiler makers, welders, riggers, and electrical technicians are getting higher doses, and at PWR 10, where welders are getting an average dose of slightly more than 1 rem. The craft workers receiving average annual doses >2 rem are typically millwrights, pipe fitters, maintenance, and inspection & control technicians.

6.2.1.2 Boiling Water Reactor Data

Typically, 700 persons at BWRs get annual whole-body doses greater than 1 rem, which is higher than for PWRs. Up to about 100 per unit get annual doses greater than 2 rem. Up to 30 have lifetime doses greater than age.

The craft workers receiving annual average whole-body doses greater than 1 rem are typically millwrights, health physics technicians, maintenance technicians, pipe fitters, and instrumentation and control technicians.

6.2.1.3 Contractor Data

Significantly more persons with higher doses were expected from the nuclear power plant contractors. However, although the numbers were larger than for nuclear power plant workers, they are not significantly different. In fact, one PWR contractor showed some of the lowest dose data.

Despite the good results for one contractor, both PWR and BWR contractors reported hundreds of people with doses greater than 1 rem yr^{-1}. One major PWR contractor reported over 300 people with dose over 2 rem yr^{-1}; however, in all other cases, the number was less than 60. Once again, the lifetime dose less than age was less frequently exceeded; only 2 contractors reported double digit figures (14 for one, 51 for the other).

The average dose for each craft can be used to determine the work groups that are receiving the higher doses. For contractors, the groups that get an average annual dose greater than 1 rem included maintenance technicians, riggers, electrical technicians, station men, radwaste handlers, and quality-assurance technicians.

7 Costs Associated With Dose Reduction Modifications in the Nuclear Power Industry

7.1 Introduction

One of the more difficult aspects of projecting the impacts of dose reduction is the estimate of costs. The ALARA Center at Brookhaven National Laboratory has been compiling and evaluating the cost and resulting dose reduction for a wide variety of reactor plant modifications since the early 1980s. The data selected for presentation indicate the basis for many of the cost estimates given in Tables 5.3 and 5.5. NUREG/CR 4373 (Baum, 1985) describes the approach taken to obtain the listed values and gives additional examples.

7.2 Costs (and the Related Dose Saved) of Selected Modifications Which Might be Employed to Reduce Exposure

The following list is taken from NUREG/CR 4373 and contains examples of items with a cost-effectiveness of $10 per person-Sv ($1,000 per person-rem) or less. Examples of less cost-effective modifications also can be found in this report.

Table 7.1 Estimated Costs and Dose Savings for Modifications at Nuclear Power Plants (Baum, 1985)

Modification	Dose Saved person-Sv (person-rem)*	Capital Cost ($)**
PWR Refueling Machine (New Plant, on Critical Path)	.9 (90)	220,000
PWR Reactor Vessel Head Multi-Stud Tensioner-/Detensioner (Two Reactor Site, on Critical Path)	16 (1,600)	940,000
PWR Reactor Vessel Head Multi-Stud Tensioner-/Detensioner (Single Reactor Site, on Critical Path)	7.9 (790)	940,000
PWR Integrated Head Assembly (New Plant, on Critical Path)	1.2 (120)	75,000
Multi-Stud Tensioners/Detensioners for PWR Reactor Pressure Vessel (on Critical Path)	2.4 (240)	600,000
PWR Reactor Vessel Head Tensioner/Detensioner (on Critical Path 25% of Time)	3.6 (360)	340,000
Steam Generator Channel Head Decontamination (Not on Critical Path)	37 (3,700)	2,145,191

* Dose savings accumulated over the useful period for the item (typically 30 years).

** In 1984 dollars. Includes the cost of replacement power for modifications that affect critical path time.

Table 7.1 Continued

Modification	Dose Saved person-Sv (person rem)*	Capital Cost ($)**
Reactor Cavity Decontamination Using the WEPA Cleaning System	.48 (48)	89,000
BWR Control-Rod-Drive-Handling Tool (on Critical Path 25% of Time)	9.4 (940)	325,000
PWR Reactor Vessel Head Tensioner/Detensioner (on Critical Path 25% of Time)	4.2 (420)	349,000
PWR Reactor Vessel Head Tensioner (on Critical Path 25% of Time)	9.6 (960)	349,000
Shredder-Compactor for Dry Active Waste	2.6 (260)	450,000
Robotics System for Remote Inspections of BWR Moisture Separator and Feedwater Pump Areas (Three Reactor Site)	21 (2,100)	66,700
PWR Quick Opening Fuel Transfer Tube Closure (New Plant, on Critical Path)	.15 (15)	1,500
Remote Readout Near PWR Seal Table	.59 (59)	89,000
PWR Steam Generator Manway Tensioner/Detensioner and Handling Device (on Critical Path 25% of Time)	4.4 (440)	500,000
Photographic Technique for PWR Steam Generator Tube Plugging Inspections	16 (1,600)	5,000
PWR Steam Generator Manway Tensioner/Detensioner	.9 (90)	133,000
Robotic Inspection of PWR Ice Condenser Area	1.5 (150)	100,000
Solid Radioactive Waste Handling Using High Integrity Containers	.51 (51)	150,000
Robotics System for Inspections in BWR Moisture Separator and Feedwater Areas (Single Reactor Site)	7 (700)	65,900
Robotic Mechanism for Surveillance of BWR High Pressure Feedwater Heater Rooms (Three Reactor Site)	1.2 (120)	22,400

Table 7.1 Continued

Modification	Dose Saved Person-Sv (person-rem)*	Capital Cost ($)**
Portable Robotic System for Smoke Detector Inspection (Three Reactor Site)	1.4 (140)	20,000
Robotic Mechanism for Surveillance of BWR High Pressure Feedwater Heater Rooms (Single Reactor Site)	.39 (39)	20,800
Portable Robotics System for Smoke Detector Inspection (Single Reactor Site)	58 (5,800)	20,000
BWR-CRD Scram Discharge Line Flange for Hydrolazing the Header	2.95 (295)	4,000
Portable Shielding System for the PWR Steam Generator Channel Heads	14.9 (1,490)	50,000
Shielding for CVCS Demineralizers (Option B)	.30 (30)	1,300
Clean Seal Cooling Water Supply for BWR Recirculation Pump	5.95 (595)	25,000
PWR Power Level Monitor Using ^{16}N Detectors	2.4 (240)	15,000
Cobalt Replacement in PWR Reactor Coolant Pumps (Three Loop Operating Plant, Pumps Replaced for Other Reasons)	5.6 (560)	30,000
Shielding for CVCS Demineralizers (Option A)	.51 (51)	2,600
Replacement of PWR Steam Generators with Low-Cobalt (<0.03%) Tubing (Three-Loop Operating Plant, Replacement Needed for Other Reasons)	35 (3,500)	198,000
Replacement of PWR Control-Rod-Drive Mechanisms with Low-Cobalt Parts (Three-Loop Operating Plant, Replacement Needed for Other Reasons)	8.1 (810)	50,000
Replacement of PWR Steam Generators with Those Having Low-Cobalt (0.015%) Tubing (Three-Loop Operating Plant, Replacement Needed for Other Reasons)	47 (4,700)	300,000
Replacement of PWR Control-Rod-Drive Mechanisms with Low Cobalt Parts (Four-Loop Operating Plant, Replacement Needed for Other Reasons)	7.7 (770)	50,000

Table 7.1 Continued

Modification	Dose Saved person-Sv (person-rem)*	Capital Cost ($)**
Replacement of PWR Steam Generators Using Low-Cobalt (<0.03%) Tubing (Four-Loop Operating Plant, Replacement Needed for Other Reasons)	37 (3,700)	264,000
Replacement of PWR Steam Generators with Those Having Low-Cobalt (0.015%) Tubing (Four-Loop Operating Plant, Replacement Needed for Other Reasons)	50 (5,000)	400,000
Temporary Shielding for PWR Reactor Vessel Head	.88 (88)	1,500
Low-Cobalt Specifications for PWR Fuel Assembly Nozzles (New Plant)	.93 (93)	10,230
Cobalt Replacement in PWR Reactor Coolant Pumps (Four-Loop Plant, Pumps Replaced for Other Reasons)	3.2 (320)	30,000
TV Robot Inspection of PWR Vessel Head (Single Reactor Site)	2.7 (270)	19,000
Reduce Cobalt Impurity in New PWR Steam Generator Tubing (Sizewell 'B" Plant)	2,700	330,000
Handling Equipment for PWR Steam Generator Manway Covers	.45 (45)	5,600
Mock-Up Training for PWR Steam Jobs	29 (2,900)	60,000
Installation of Viewing Windows in BWR Plants	2.24 (224)	25,000
PWR Reactor Pressure-Vessel Head Laydown Shield	.9 (90)	15,000
BWR Control Rod Drive Disassembly and Decontamination Tank	2.68 (268)	35,000
Permanent Shield for PWR Reactor Vessel Head (Three Reactor Site)	8.9 (890)	185,000
Electropolishing Tank for BWR Control Rod Drives	2.99 (299)	40,000
Relocation of Instrument Readout at PWR Spent-Fuel Pit Heat Exchanger	.13 (13)	2,500

Table 7.1 Continued

Modification	Dose Saved person-Sv (person-rem)*	Capital Cost ($)**
Helium Leak Detection for BWR Condenser Tubes	1.8 (180)	25,000
Relocation of Fuel Sipping Cans	.3 (30)	5,000
Shielding for PWR Reactor Upper Internals (Two Reactor Site)	.84 (84)	19,500
Ultrasonic Testing of PWR Pressurizer Surge Line (Three Reactor Site)	.17 (17)	8,000
PWR Reactor Vessel Head Shielding (No Critical Path Expense)	2 (200)	65,321
PWR Steam Generator Tube Inspection and Repair Robot	23 (2,300)	450,000
BWR Pipe Insulation Improvements for In-Service Inspections	3.9 (390)	100,000
TV Monitor for BWR Cleanup Heat Exchanger Room	2.5 (25)	7,000
BWR Control Rod Drive Handling Tool	9.4 (940)	325,000
PWR Reactor Vessel Head Shielding (On Critical Path)	2 (200)	95,321
Acoustic Emission Instrumentation for ISI of the Reactor Vessel and Reactor Coolant Piping	13 (1,300)	450,000
Decontamination of a BWR Recirculation System	9 (900)	750,000
Air-Cooled Anticontamination Suit, Radio Dosimetry, and Radio Communications	1.5 (150)	56,000
Shielding for PWR Reactor Upper Internals (Single Reactor Site)	.41 (41)	19,500

* Dose savings accumulated over the useful period for the item (typically 30 years).
** In 1984 dollars. Includes the cost of replacement power for modifications that affect critical path time.

7.3 Estimated Impacts

During the 1980s, considerable efforts were made by the nuclear industry to reduce collective and individual doses at nuclear power plants. This effort was stimulated by several factors, including anticipated lowering of dose limits to conform with the 1977 ICRP recommendations, the reassessments of risks based on new dosimetry and epidemiological data on the Japanese survivors of the World War II atomic weapons, and anticipated further restrictions on annual and lifetime dose limits.

These pressures led the U.S. utilities to expend significant sums on dose control modifications of the type illustrated in Table 7.1. The judgements on cost-effectiveness were generally based on a valuation of the dose avoided, that was in the range of a few hundred thousand dollars to about $2.6 million per person-Sv saved (Baum, 1991). Figure 7.1 summarizes the values employed at nuclear power plants in 1991-1992 (Kindred, 1992).

These high monetary values of the cost or value of dose savings were based primarily on the costs of hiring additional workers that were necessitated by lower administrative dose limits. For example, a worker hired at a cost of $53,000[2] per year who might be permitted only 40 mSv (4 rem) (typical administrative limit) exposure per year leads to a cost of dose avoided of $53,000/.04 Sv = $1,325,000 person-Sv ($13,250 per person-rem). Not all workers would be near the administrative limits and a worker's productivity may not drop to zero when the limit is reached, so the adopted value of cost for dose avoided for a particular job or plant is usually less (e.g. average = $434,300 per person-Sv ($7,343 per person-rem on Figure 7.1).

Figure 7.2 shows the total number of reactors and total collective dose for commercial nuclear plants from 1973 through 1989 (Hinson, 1992). While the number of reactors increased from 68 in 1980 to 112 in 1992, the collective dose decreased from about 540 per person-Sv (54,000 per person-rem) to about 280 per person-Sv (28,000 per person-rem); or collective dose per reactor decreased from about 7.94 per person-Sv (794 per person-rem yr^{-1}) in 1980 to about 2.5 per person-Sv yr^{-1} (250 per person-rem yr^{-1}) in 1991. Assuming this reduction was at an average cost of $700,000 per person-Sv ($7,000 per person-rem), the cost is about 544 (794-250) person rem per reactor per year x $7,000 per person rem = $3,808,000 per reactor per year. Many dose reduction efforts in the past did not require the $700,000 per person-Sv ($7,000 per person-rem) expenditure. However, because many of the less costly modifications have already been implemented, it is likely that future reductions will require the higher expenditure. Thus, for the nuclear power industry one can anticipate that the impact of any lower dose rates are likely to be proportional to the product of the collective dose being received above the new limit and about $700,000 per person-Sv
($7,000 per person-rem).

Table 4.5 shows that there were 8,845, 1,290, 121, and 11 persons in 1989 who received between 1.0-2.0, 2.0-3.0, 3.0-4.0, and 4.0-5.0 rem, respectively. The collective dose above 1 rem yr^{-1} received by these individuals is estimated as 16,420 person-rem, assuming that the average dose for each group is equal to the midpoint for that dose range (e.g. average dose for the 1.0-2.0 dose range is 1.5 rem).

If a 10 mSv (1 rem yr^{-1}) limit were imposed, it would require a collective dose reduction of 164.2 person-Sv (16,420 per person-rem). This would cost:

$$\frac{164.2\,\frac{Sv}{yr}\,x\,\frac{700,000}{Sv}}{112\ reactors} = \frac{\$1,026,000}{reactor\ year}$$

For a 20 mSv yr^{-1} (2 rem yr^{-1}) limit, the required collective dose reduction would be about 33.69 person-Sv yr^{-1} (3,369 person-rem yr^{-1}). This would cost:

$$\frac{33.69\,\frac{Sv}{yr}\,x\,\frac{700,000}{Sv}}{112\ reactors} = \frac{\$210,000}{reactor\ year}$$

The impact of imposing an "age x 1" limit on workers cumulative effective dose is difficult to judge from the limited data. Two estimates are made to indicate a likely range.

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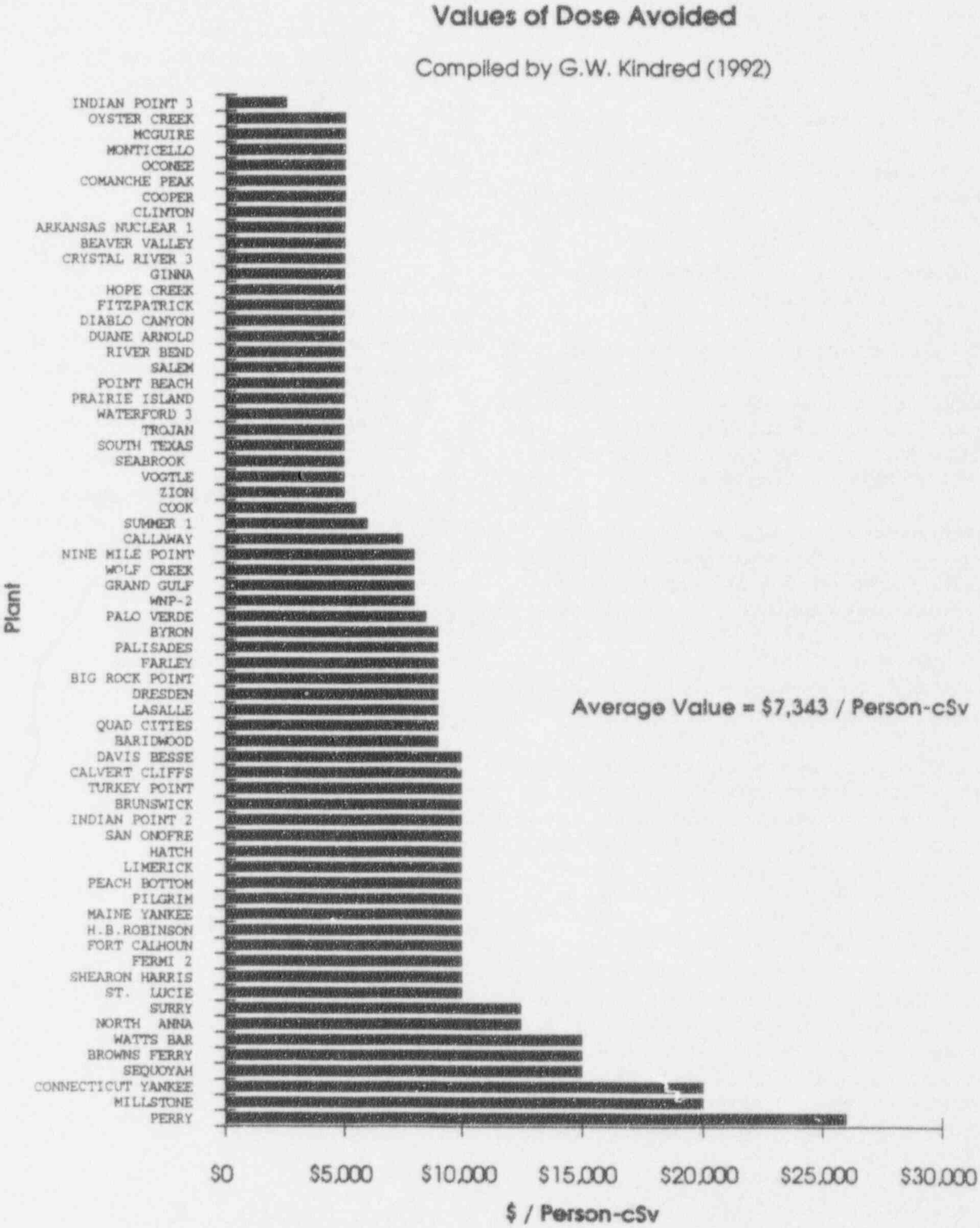
[2] Fully loaded cost for operating and maintenance personnel expressed in 1984 dollars including all fringe benefits, but not including overhead and general and administrative expenses (Ball, et al, 1984).


Values of Dose Avoided
Compiled by G.W. Kindred (1992)
INDIAN POINT 3
OYSTER CREEK
MCGUIRE
MONTICELLO
OCONEE
COMANCHE PEAK
COOPER
CLINTON
ARKANSAS NUCLEAR 1
BEAVER VALLEY
CRYSTAL RIVER 3
GINNA
HOPE CREEK
FITZPATRICK
DIABLO CANYON
DUANE ARNOLD
RIVER BEND
SALEM
POINT BEACH
PRAIRIE ISLAND
WATERFORD 3
TROJAN
SOUTH TEXAS
SEABROOK
VOGTLE
ZION
COOK
SUMMER 1
CALLAWAY
NINE MILE POINT
WOLF CREEK
GRAND GULF
WNP-2
PALO VERDE
BYRON
PALISADES
FARLEY
BIG ROCK POINT
DRESDEN
LASALLE
QUAD CITIES
BARIDWOOD
DAVIS BESSE
CALVERT CLIFFS
TURKEY POINT
BRUNSWICK
INDIAN POINT 2
SAN ONOFRE
HATCH
LIMERICK
PEACH BOTTOM
PILGRIM
MAINE YANKEE
H.B.ROBINSON
FORT CALHOUN
FERMI 2
SHEARON HARRIS
ST. LUCIE
SURRY
NORTH ANNA
WATTS BAR
BROWNS FERRY
SEQUOYAH
CONNECTICUT YANKEE
MILLSTONE
PERRY
Plant
Average Value = $7,343 / Person-cSv
$0
$5,000
$10,000
$15,000
$20,000
$25,000
$30,000
$ / Person-cSv

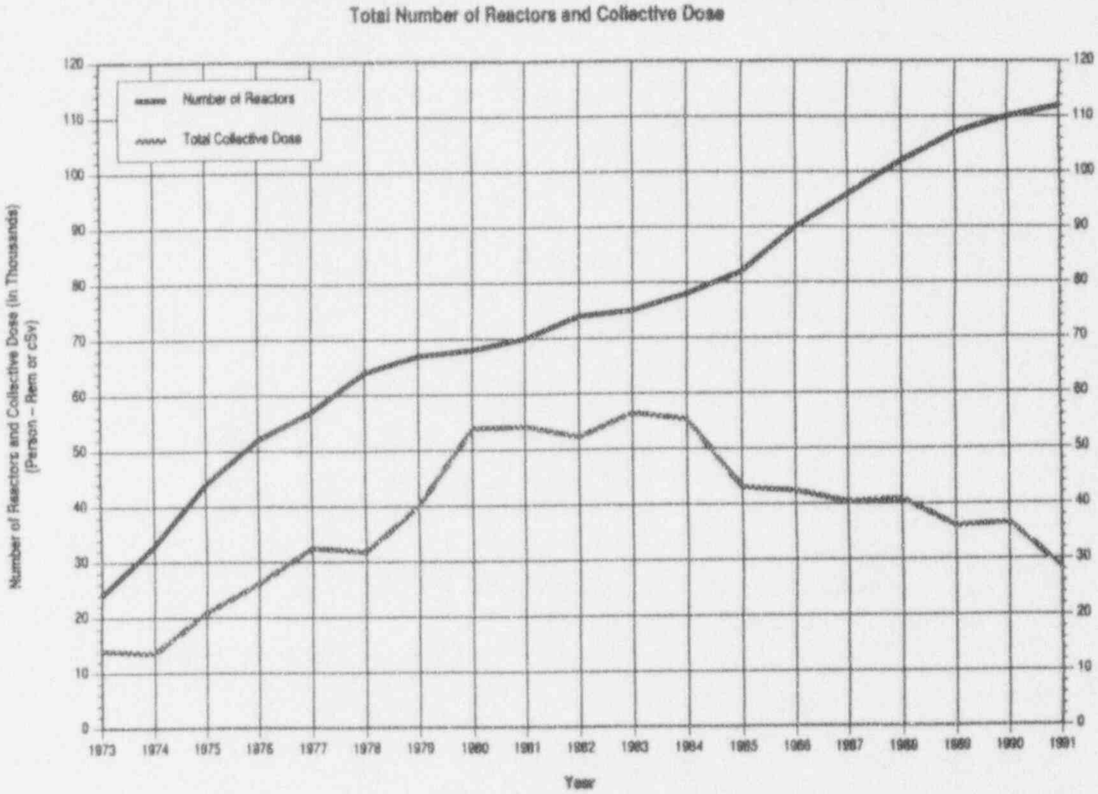


Figure 7.2 Total Number of Reactors and Collective Dose

The first estimate is based on the number of workers who exceed the age limit in the high dose groups in the survey of 22 reactors (Section 6). There were 76 individuals in the 13 PWRs and 67 in the 9 BWRs who exceeded the age limit, a total of 143. Assuming each of these workers were replaced at an annual cost of \$53,000, and that these replacements were sufficient to provide the crews needed to work under new limits, the annual cost per reactor would be about:

$$\frac{143 \, x \, \$53,000}{22} = \frac{\$344,500}{reactor\ year}$$

Since the replaced workers would be useful for other work (not high dose), this cost estimate is an upper limit.

The second estimate assumes that workers currently exceeding their age limit would be given an exception to the age rule (a "grandfathering" clause) and would stay below either 10 mSv (1 rem) yr^{-1} or 2 rem yr^{-1} limit. The cost was estimated by considering the cost of implementing these limits and the number of workers affected for each limit in the sample survey of Section 6.

The number of workers exceeding 10 mSv yr^{-1} (1 rem yr^{-1}) and 20 mSv yr^{-1} (2 rem yr^{-1}) were 3,417 and 874, respectively. Assuming the replacement worker and dose reduction costs per worker are the same for those exceeding the age limit and those exceeding the 10 mSv (1 rem) and 20 mSv (2 rem), annual limits, the costs for an age limit with "grandfathering", can be estimated from the ratios of workers in the various groups and the earlier cost estimates.

Costs

Compared to the 10 mSv (1 rem) yr^{-1} cost estimates:

$$\frac{143}{3,417} x \$1,026,000 \approx \frac{\$43,000}{\textit{reactor year}}$$

Compared to the 20 mSv (2 rem) yr^{-1} cost estimates:

$$\frac{143}{874} x \$210,000 \approx \frac{\$34,000}{\textit{reactor year}}$$

These two estimates are nearly equal and can be rounded to about $40,000 per reactor per year for a 50 mSv yr^{-1} limit with an "age x 1" (rem or 10 mSv) cumulative limit.

In summary, the estimated cost impacts on nuclear power plant operations for the three dose limit options considered are (rounded to one significant figure):

Option	Estimated Cost Per Year Per Reactor
10 mSv (1 rem) yr^{-1} limit	≈ $1,000,000
20 mSv (2 rem) yr^{-1} limit	≈ $ 200,000
Age 10's of mSv (Age x 1) with a 50 mSv (5 rem) yr^{-1} limit	≈ $ 40,000 with "grandfathering" ≈ $ 300,000 without "grandfathering"

8 Summary

As in Section 5, the conclusions will be given by practice and industry type, followed by a general conclusion. In general, the options used in the questionnaire will guide this presentation except that the 20 mSv yr^{-1} (2 rem yr^{-1}), coupled with the age limitation option, will not be used, because it differs very little with a 20 mSv yr^{-1} (2 rem yr^{-1}) limit.

8.1 Medical/Dental/Veterinary

8.1.1 1 Rem Yr^{-1}

Although several issues raised in the comments reflected a general feeling that there was no biological need for reducing the dose limit, UNSCEAR (UNSCEAR,1988), BEIR (NAS BEIR, 1990), and ICRP (ICRP, 1991) indicated differently. Overall, the estimated costs were moderate, even with the most severe limitation of 10 mSv yr^{-1} (1 rem yr^{-1}). However, selected occupational groups within the medical community would be severely impacted, specifically, cardiologists and interventional radiologists. Indeed, one comment suggested that their exposure may be underestimated due to the lack of compliance with personal monitoring procedures.

8.1.2 2 Rem Yr^{-1}

The vast majority of respondents considered that 20 mSv yr^{-1} (2 rem yr^{-1}) was attainable, although there were clearly costs associated with this option. Significantly, the assessment of dose was raised by several respondees. It is still too often the case that the exposure to the badge worn on the collar by an individual wearing a lead apron is used for determining compliance with dose limits. UNSCEAR (UNSCEAR, 1988) suggests that in diagnostic radiology the dosimeter usually overestimates the effective dose by about 2-4. Although this issue needs to be addressed, it gives some support to the suggestion that the impact of lowering the doses would not be severe if the dose were assessed appropriately. Anticipated NCRP guidance on the effective dose equivalent from partial body exposure may resolve some of these issues.

There was a comment that better training of selected medical personnel could reduce their exposure at little additional cost.

8.1.3 5 Rem Yr^{-1} and Cumulative Dose in Rem Less Than Age in Years Limit

The respondents were unanimous in their assessment that 50 mSv yr^{-1} (5 rem yr^{-1}), coupled with the restriction on the cumulated dose in 10s of mSv (or in rem) not exceeding their age in years, is without serious impact. We note that in Figure 4.15 indicates that women workers in medicine appear to receive more radiation as they grow older. However, due to low average exposure to medical workers, the age limitation on dose should not have an important impact.

We also note that this category does not include those medical workers whose job consists of making cyclotron-produced radiopharmaceuticals; they are treated in Section 8.5 on manufacturing and distribution.

8.2 Nuclear Power Reactor Plants and Their Contractors

There are many sources of information on this category of workers. For this report, the following studies were reviewed: The EEI study, which was based on 27 responses to a survey; the BNL high-dose group study, which was based on 22 power plant site responses; the questionnaire results, based on 18 responses; the NRC REIRS data, which provides dose distribution data on nuclear power and contractor workers; and the 1984 EPA report, which examined the available dosimetric data from a variety of view points, such as cumulative exposure as a function of age and sex. The cost data given in NUREG/CR-4373 were used to evaluate the cost estimates.

8.2.1 1 Rem Per Yr^{-1}

A 10 mSv yr^{-1} (1 rem yr^{-1}) dose limit would have enormous impacts in the nuclear power industry, even to the point of being impossible without unreasonable costs for most existing facilities. The REIRS data for 1990 given in Table 4.5 indicate that nearly 10% of the LWR workers with measurable exposure exceeded 10 mSv yr^{-1} (1 rem yr^{-1}), as does Table 5.4 from the questionnaire. Tables 6.1 and 6.2 indicate that in the 22 nuclear power plant sites participating in the high-dose worker study, nearly 6,000 workers had annual exposures exceeding 10 mSv (1 rem) in 1988.

As expected, this is even more critical for craft workers, as shown in Tables 6.3 and 6.4 from the BNL high-dose group study. For the 22 plant sites, there are 3,500 craft workers in high-dose groups with an annual exposure over 10 mSv (1 rem). For example, there were 1,400 millwrights, 455 maintenance techs, and 315 health physics techs all in excess of 10 mSv yr^{-1} (1 rem yr^{-1}).

This should not be taken to mean that the next generation of nuclear power plants cannot be designed to operate with exposure below 10 mSv yr^{-1} (1 rem yr^{-1}), but with the current plants it is unlikely to be economically feasible. For example, the EEI Report found that at this level, "all responders felt operations would be extremely difficult, if not impossible" (EEI 1991).

8.2.2 2 Rem Yr^{-1}

A limit of 20 mSv yr^{-1} (2 rem yr^{-1}) would also appear to be very difficult to achieve for the nuclear power industry, although just over 1000 workers exceed 20 mSv yr^{-1} (2 rem yr^{-1}), (Table 4.5 from the REIRS data). Figures 4.1 and 4.2 show that the utility personnel (UT) would not be as severely affected as the contractors (TO). The high-dose group study also indicates that the craft groups would, again, have the highest percentage of people exceeding 20 mSv yr^{-1} (2 rem yr^{-1}). The responses to the questionnaire indicate that the impact at 20 mSv yr^{-1} (2 rem yr^{-1}) would be about half that at 10 mSv yr^{-1} (1 rem yr^{-1}), but still several million dollars per plant in capital costs, nearly half a million dollars per plant in annual costs, and a 2 to 100% increase in collective dose.

The greatest diversity was seen here among responders. For utilities which do not perform their own major maintenance, the impact is not too great. For utilities that do, and for contractors supplying skilled craft workers, the impact is far greater. Questions were raised in both the EEI Report and the questionnaires about the availability of skilled personnel at this dose limit. Even utilities who felt they could live with a 20 mSv yr^{-1} (2 rem yr^{-1}) limit noted that additional personnel would be needed. For this dose limit option the issue is practicality. Unlike the 10 mSv yr^{-1} (1 rem yr^{-1}) limit, it would be possible, but expensive, both in capital cost and in increased collective dose. Many more skilled craft workers would be needed to work on vital safety systems, yet the supply is already limited. At such a dose limit, there might be potentially serious impacts on safety since some inspections and maintenance might be curtailed. In general, such a dose limit would require an extensive change in the way modifications are made and maintenance is done. System decontamination, remote tooling, and robots would be essential. This can be summed up by one of the comments from Section 5.2, "Two rem/yr would be difficult and costly but achievable for utility workers. However, for contract personnel, it would be very difficult and exceedingly costly."

8.2.3 5 Rem Yr^{-1} and Cumulative Dose in Rem Less Than Age in Years Limit

The REIRS data as given in Table 4.5 for 1990 indicates that none of the LWR workers exceeded 50 mSv yr^{-1} (5 rem yr^{-1}). The REIRS does not contain cumulative dose data. This study's questionnaire data indicates virtually no impact under this limit; although, the comment given in Section 5.2 notes that some sort of grandfathering is needed - "For those individuals who would exceed the lifetime limit of age in rem, a 2 rem/year limit would be necessary to maintain their employment in the industry." The need for "grandfathering" also is shown in Tables 6.3 and 6.4 on the high-dose groups where 143 workers are shown to exceed their lifetime limit. The data in the EEI Report suggests a concern about contractor availability.

There is a hidden aspect of the age in rem limit. It is noteworthy that, in effect, the worker will have to average less than 15 mSv yr^{-1} (1.5 rem yr^{-1}) over the working lifetime. This is somewhat ameliorated by data from the EPA Report that suggests that for males (most workers in the nuclear industry) the average exposure received each year decreases with age after age 42 (Table 4.6). For female workers (primarily in medicine) there is no decrease, although their mean annual dose is less than half that of male workers.

The 50 mSv yr^{-1} (5.0 rem yr^{-1}) and age in 10s of mSv (rem) limit together with a "grandfather clause," which permits 20 mSv yr^{-1} (2 rem yr^{-1}) after exceeding the age limits, seems acceptable, because it would have very little impact on either the industry or the individual worker. Such a "grandfathering" exception would have to be closely controlled, since the risk to such workers could conceivably be in excess of the risk of accidental death of workers in more hazardous industries in the United States.

8.3 Test and Measurement Including Industrial Radiography

The data were obtained from responses to the questionnaire, from the REIRS, and from discussions in the working committee. Table 4.2, from the REIRS data, shows a substantial difference in the dose received between single versus multiple locations. The data given in Table 5.7 seems to reflect the status for multiple locations. The protection problems are more variable with multiple locations and the potential for unintended exposure is greater.

8.3.1 1 Rem Yr^{-1}

At a 10 mSv yr^{-1} (1 rem yr^{-1}) limit, there will be moderate increases in collective dose and in cost for both modification and operating radiation protection programs (Table 5.7). The responders indicated (Table 5.8) that about 10% of the employees with measurable dose received exposures in excess of 10 mSv yr^{-1} (1 rem yr^{-1}).

8.3.2 2 Rem Yr^{-1}

Here, the impact seems smaller. Some increase in radiation protection costs were projected by three of the respondents, although most thought they could operate with this option. The data for 1989 (Table 5.8) indicates that 4% of the workers exceed 20 mSv yr^{-1} (2 rem yr^{-1}).

8.3.3 5 Rem Yr^{-1} and Cumulative Dose in Rem Less Than Age in Years Limit

For this option, there would be no impact expected in collective dose, facility modification, or radiation protection. This suggests that many of the higher annual doses were inadvertent, and that the same individuals were unlikely to receive such exposure very often during their working lifetime.

8.4 Universities not Including Medical, Dental, or Veterinary Schools

The data here were obtained from the questionnaires and the working committee. Although there were few, the working committee felt the impacts were unlikely to differ very much from those reflected in the questionnaire survey.

8.4.1 1 Rem Yr^{-1} Limit

Although there was no projected increases in collective dose, one respondent suggested that there would be some costs for facility modification and some increase in radiation protection costs.

8.4.2 2 Rem Yr^{-1} Limit

Here, there apparently would be no impact either on the collective dose or on the facility modification; however, some increase in radiation protection costs was reflected by one of the respondents.

8.4.3 5 Rem Yr^{-1} and Cumulative Dose in Rem Less Than Age in Years Limit

No impact was seen for this dose limitation option.

8.5 Manufacturing and Distribution Including Cyclotron-Produced Radiopharmaceuticals

This data came from responses to the questionnaire as given in Table 5.11 and 5.12, from the REIRS data given in Table 4.4, and from the working committee. Material submitted by one medical respondent which dealt with cyclotron-produced radiopharmaceuticals, was included in this category, and the average measurable dose (calculated from Table 5.12 from the questionnaire results) is more than double that given in Table 4.4 from the REIRS Report. This difference may be due to the inclusion of cyclotron workers in Table 5.12, which are not necessarily included in Table 4.4 (they may not be operated by NRC licensees).

8.5.1 1 Rem Yr^{-1} Limit

This group of workers is one of the more highly impacted groups, with the respondents and the working committee suggesting there would be substantial increases in collective dose, in facility modifications, and in annual radiation protection costs.

8.5.2 2 Rem Yr^{-1} Limit

Here the impact was substantially reduced; however, there still will be important costs both in terms of collective dose, facility modification, and radiation protection. One respondent specifically noted, "...If extremities are lowered by 2/5, as above, we would have large expenses..." Also, there is concern about the feasibility of operating positive ion cyclotrons under this option.

8.5.3 5 Rem Yr^{-1} and Cumulative Dose in Rem Less Than Age in Years Limit

The respondents felt there would be no impact for this dose limitation, although one comment noted special exposure limits may be needed for workers who produce isotopes with cyclotrons.

8.6 Waste Management

The data are very sparse because there were only two U.S. and one non-U.S. respondents. The REIRS data (Table 4.1) reflects low exposure for those reporting to the NRC (only 119 workers with measurable exposure). Exposure which occurs at the generator site is not included.

8.6.1 1 Rem Yr^{-1} Limit

Collective dose and radiation protection costs are expected to increase under this dose limit. Table 5.14 indicates that 20% of workers with measurable dose exceeded 1 rem yr^{-1}.

8.6.2 2 Rem Yr^{-1} Limit

Collective dose, facility modification costs, and radiation protection costs are all expected to increase slightly.

8.6.3 5 Rem Yr^{-1} and Cumulative Dose in Rem Less Than Age in Years Limit

Collective dose, facility modification costs, and radiation protection costs are not expected to increase.

8.7 Fuel Fabrication, UF_6 Production

Again, the data are relatively sparse, but over 817 employees with measurable dose were included in the responses. It is extremely important to note that most dose records for this category of workers, i.e. that are given in the REIRS report and in the questionnaire, do not include internal exposure as required under the revised 10 CFR part 20. The impact of any change in limits is expected to be severe. From the comments Section of 5.8, the addition of external and internal exposure can be expected to increase reported individual exposures by 10.

8.8 Well Logging

The data from the questionnaire came primarily from a member of the working group, based on a personal survey.

For each exposure limit option, there would be no impact on collective dose, facility modification costs, nor radiation protection. The comment given in Section 5.9 is particularly important: "few well logging technicians are over 40 years of age, and the average tenure of a technician is about ten years. Therefore, the 5 rem yr^{-1} and lifetime limit would seem to be achievable, although more data are needed."

8.9 Conclusions

There would be little impact on collective doses, facility modification costs, or annual radiation protection costs under the combined 50 mSv yr^{-1} (5 rem yr^{-1}) and cumulative dose in 10s of mSv (rem) equal to age in years limit. We point out that the lifetime risk associated with this option - to an individual maximally exposed - would be slightly less than that incurred by a similar individual controlled by the ICRP's limit of 100 mSv in 5 years (10 rem in 5 years). However, a "grandfather" clause allowing up to 2 rem yr^{-1} after exceeding the age limit may be needed for several hundred workers in order for them to continue as radiation workers.

A 20 mSv yr^{-1} (2 rem yr^{-1}) limit would appear achievable, although some tasks, particularly in medicine and power reactor maintenance, might prove extremely difficult to perform. In addition, extensive modifications would be required for many tasks, including the use of robots and remote tools. Depending upon the extent of the modifications made, the collective dose could increase or decrease. That is, extensive remote tooling and facility modifications might lower collective dose. Less ambitious modifications, and less use of remote tooling might keep the collective dose at about the same level while reducing individual doses; lastly, making no changes and allowing the same tasks to be performed would result in higher collective doses.

There has been a suggestion that for a 10 mSv yr^{-1} (1 rem yr^{-1}) limit, the risk to the most highly exposed individual would be lower than for other options (i.e. equivalent to that in safe industries), but the impacts are expected to be quite serious for many of the industries which responded to the questionnaire. Some tasks in nuclear power, fuel fabrication, and medicine could not be performed under present procedures. For industries with large source terms, facility modifications and radiation protection costs are expected to be extremely large. From a trade-off between the costs of facility modifications and radiation detriment, collective dose may increase substantially.

This summary has focused on the high-dose issues. Many respondents to the questionnaire, however, felt that a 10 mSv yr^{-1} (1 rem yr^{-1}) limit was entirely feasible. This diversity in potential exposure led the ICRP to recommend applying dose constraints. Such annual dose constraints would be imposed by regulating authorities on specific licensees, based on their source terms, potential for exposure, and costs incurred. Exceeding such constraints would lead to regulatory action. Such a procedure assures that those licensees who can keep below 50, 20, 10 mSv (5,2,1 rem), do so, while recognizing that some operators can not. These latter must have the ability to use the full dose limit.

Two additional issues must be kept in mind when assessing the impact of lower dose limits. The first is that licensees may establish administrative limits below the regulated dose limits. For example, with a regulatory limit of a 50 mSv yr^{-1} (5 rem yr^{-1}), an administrative limit of a 40 mSv yr^{-1} (4 rem yr^{-1}) might be imposed. With a 20 mSv yr^{-1} (2 rem yr^{-1}) limit, a 15 mSv yr^{-1} (1.5 rem yr^{-1}) administrative limit might be used, and so on.

There are two worker groups, transportation workers who frequently handle packages containing radioactive materials, and aircraft crews, which have not been traditionally included under individual dose limitation, which deserve brief mention here, because the reduction in occupational dose limits could affect them.

Exposures to transportation workers have been controlled by limiting both the quantity of radioactive materials (to reduce ingestion of radionuclides) and the external dose rate (to reduce external dose to those workers and to passersby). The bases for the radiation for limits on packages are now relatively obsolete, since they were established on the 5 mSv yr^{-1} (500 mrem yr^{-1}) limit for the public and 15 mSv yr^{-1} (1.5 rem yr^{-1}) limit for workers. Published data suggests that actual experience in terms of doses to these workers shows that there is not an issue of impact here, but the IAEA might be advised to review their basic criteria documents for transportation of radioactive material against today's risk estimates and any new dose limits suggested.

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Questionnaire on the Impact of Reduced Dose Limits at Your Facility

Possible Dose Limit				
Estimated Impacts:	2 rem y^{-1}	1 rem y^{-1}	Cumulative < age and 5 rem y^{-1}	Cumulative < age and 2 rem y^{-1}
Will collective dose change? Y, N; Up, Down; Estimate				
Facilities Modifications needed? Y, N; and est. costs				
Increase Rad. Protection? Y, N; and est. costs				

Your 1989 experience:

Number of Employees with Annual Doses:

>5 rem _____ >2 rem _____ >1 rem _____

Number of Employees with Lifetime Dose Greater Than Age in Rem: ____________

Number of Employees with Measureable Dose: ____________

Annual Collective Dose: ____________

Comments and Suggestions:

____

____

____

Would you be willing and available to particpate in a working group to review and assess the results of this questionnaire?
Yes _____ No _____

Please indicate which of the following apply to your organization:

- ☐ Medical/Dental
- ☐ Veterinary
- ☐ University
- ☐ Other Research & Development
- ☐ Well Logging
- ☐ Manufacturing/Distribution
- ☐ Naval Nuclear Propulsion Program
- ☐ Other Military & their Contractors
- ☐ Nuclear Power Reactors & their Contractors
- ☐ Test & Measurements
- ☐ Mining and Milling
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- ☐ Waste Management & Disposal
- ☐ Research and Test Reactors
- ☐ Other (Specify) __________

Please provide additional description of your organization where the primary category is insufficient, e.g., x-ray therapy, radiopharmacy, reactor refueling, etc.: ____________________________

Name & Title: ____________________________

Company: ____________________________

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Please fold and return with any additional comments to Charles B. Meinhold, Radiological Sciences Division, Brookhaven Naitonal Laboratory, Building 703M, Upton, New York 11973. Telephone: (516) 282-4425, FAX (516) 282-5810.

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10. SUPPLEMENTARY NOTES

11. ABSTRACT (200 words or less)

This report summarizes information required to estimate, at least in qualitative terms, the potential impacts of reducing occupational dose limits below those given in 10 CFR 20 (Revised). The data from a questionnaire developed for this project and data from existing surveys were used to estimate the impact of three dose limit options; 10 mSv yr^{-1}, 20 mSv yr^{-1}, and a combination of an annual limit of 50 mSv yr^{-1} coupled with a cumulative limit in rem equal to age in years.

The overall conclusions of the study are: (1) Although 10 mSv yr^{-1} is a reasonable limit for many licensees, such a limit could be extraordinarily difficult and potentially destructive to some, (2) Twenty mSv yr^{-1} as a limit is possible for some of the latter groups, but for others it would prove difficult, (3) Fifty mSv yr^{-1} and age in 10's of mSv would appear acceptable both in terms of the related lifetime risk of cancer and severe genetic effects to the most highly exposed and in terms of practicality of operation. This acceptability in some segments of the industry is based on the adoption of a "grandfather clause" for those exceeding the cumulative limit.

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